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Structured proficiency based progression phacoemulsification training curriculum using virtual reality simulator technology

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Structured Proficiency Based Progression Phacoemulsification Training Curriculum Using Virtual Reality Simulator Technology

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DECLARATION

I declare that this thesis, which I submit to RCSI for examination in consideration of the award of a higher degree Master in Surgery (MCh) is my own personal effort. Where any of the content presented is the result of input or data from a related collaborative research programme this is duly acknowledged in the text such that it is possible to ascertain how much of the work is my own. I have not already obtained a degree in RCSI or elsewhere on the basis of this work. Furthermore, I took reasonable care to ensure that the work is original, and, to the best of my knowledge, does not breach copyright law, and has not been taken from other sources except where such work has been cited and acknowledged within the text.

Signed ____________________

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Abstract

The current method of surgical training is based on the Halstedian model where novice surgeons learn by observing and performing surgery under supervision. Cataract extraction by phacoemulsification is a type of minimally invasive surgery where direct observation is inadequate in revealing how things are done. Operating under the microscope takes away the direct hand-eye coordination. During the operation, a novice surgeon has to pay disproportionate amount of attention to psychomotor performance, depth and spatial judgment, operative judgment and decision-making, comprehending instruction, and gaining additional knowledge. The attentional capacity quickly becomes saturated, leaving very little to spot dangers ahead or to get out of difficulty situation. Consequently, patients are at higher risk when novice surgeons perform the operation.

The solution to improve novice surgeon's attentional capacity is to pre-trained pertinent operative skills in a controlled setting using simulator technology. EYESi phacoemulsification simulator offers high fidelity rendition of intra-ocular microsurgical environment. Novice surgeons can practice on the simulator until proficiency level is achieved.

The aim of this project is to design and validate didactic and skill training curriculum for cataract surgery. The didactic curriculum employs 3-dimentional animations in order to explain complex surgical procedures. The proficiency level for skill training is set based on the simulator performance of ten expert cataract surgeons. A structured proficiency based simulator curriculum is designed and validated with randomized control trial in this study.

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INTRODUCTION

History Of Cataract Surgery

The modern cataract surgery is a result of more than 2500 years of evolution and progressive development. The removal of opaque lens has been documented in Sanskrit as early as 500 B.C. in the form of couching.[1] Couching is a non-invasive but crude procedure performed by applying an external digital pressure on the cornea. In order for this procedure to be effective, the lens has to be hyper-mature with weak zonules so that when a sudden forceful external pressure is applied on the cornea, the entire lens dislocates posteriorly into the vitreous. The intact capsule prevents the development of uveitis in the vitreous cavity. In 29 A.D., the use of needling or discission was employed to break up the cataract into smaller particle to facilitate gradual absorption. This method is applicable to softer cataracts.

In 1748, Parisian Jacques Davie first described a surgical method of removing cataract that formed the basis of the modern concept for cataract surgery.[2] He introduced a form of extracapsular cataract surgery where the capsule was opened and the inner content of the lens material was removed partially while leaving the capsule in situ. In 1753, Samuel Sharp of London described an early form of intracapsular cataract extraction where he removed the entire lens through a large corneal incision. As the cornea is populated with sensory nerves, it was a very painful procedure. An assistant was needed to hold the patient down until the surgery was over. The anesthetic effect of cocaine was discovered serendipitously in 1884. Only then did the cataract surgery procedure become a less traumatic experience to endure.

As technology advanced various ways were tried to remove cataracts. In 1957, Barraquer used alpha-chymotrypsin to enzymatically dissolve the zonules for removal of the lens.[3] In 1961, Krawicz used a cryo probe to freeze the surface of the capsule to facilitate removal of the lens. The problem associated with cataract surgery up until then was a large corneal incision resulting in long recovery time and high post operative astigmatism. The absence of focusing mechanism post cataract removal also resulted in poor visual rehabilitation.

There were two major inventions in the 20th century that shaped the current method of cataract surgery. The first was the invention of artificial intraocular lens (IOL) by Dr. Harold Ridley in 1949.[4] The second was the invention of phacoemulsification by Dr. Charles Kelman in 1967. Both of these inventions were a result of careful observations and ingenuities in applying technology used in other medical fields for the furtherance of ophthalmic surgery.

Up until the invention of artificial IOL, the aim of cataract surgery was to remove the opaque lens so light could reach the retina. However, the lack of focusing mechanism means that the eye still cannot form a clear image. The implantation of artificial IOL restores the focusing function of the lens thus the light can once again form a clear image on the retina. The first successful artificial IOL implantation took place in St. Thomas' Hospital on the 29th November, 1949. Despite initial success for a series of patients, the use of this device did not gain a wider acceptance until 1970s. The main reasons for this were poor initial lens design and fierce opposition and scepticism from within the ophthalmic community.

The invention of phacoemulsification was a result of the clever application of technology available in other medical fields. The idea of breaking up lenticular materials with ultrasonic energy came to Dr. Charles D. Kelman while he was on a dental chair when the dental surgeon used a high pitched ultrasonic probe to remove dental plaques.[5] Prior to this invention, intracapsulor and extracapsulor cataract extraction were the standard practice. Phacoemulsification supplanted these procedures because of its ability to extract the lens material with very small incisions while preserving the integrity of the capsule for IOL implantation. This new technique went through a phase of improvement before it was accepted as safe and effective. The high success rate and patient satisfaction made phacoemulsification the most preferred method of cataract extraction performed by ophthalmic surgeons.[6]

Both the invention of artificial IOL and phacoemulsification technology revolutionized the practice of ophthalmology. These are the fruits of the clever application of the advance in modern technology. Today, in a similar fashion, advances in computer virtual reality technology are revolutionizing methods of surgical training.

Cataract Surgical Training

The current ophthalmic surgical training is largely based on Sir William Halsted method of apprenticeship which started at Johns Hopkins Hosptial in 1889.[7] Under this method, trainees are introduced to a surgical procedure step-by-step under the supervision of a master surgeon. The emphasis is on the hands-on experience. The Halstedian training method is effective because there is no other teaching model that can replicate the real human tissues and surgical environment. Therefore, up until recently, the prevailing method of surgical training is in the theatre with live patients.

Phacoemulsification can be divided into ten distinctive steps: draping, corneal wound construction, continuous circumlinear capsulorrhexis, hydrodissection, sculpting and dividing, segment removal, irrigation and aspiration, intra-ocular lens insertion, removal of visco-elastics, and wound closure. The choice of which step to learn first is largely at the preference of the master surgeon. In phacoemulsification surgery, training using this method is effective and produces satisfactory visual outcomes depite the fact that the trainees' rate of complication is higher than that of the experienced surgeons.[8]

The main draw back for this method is that the learning curve of a cataract surgeon takes place mainly on real patients. Phacoemulsification is a type of minimal access surgery that requires a fairly complex coordination of eyes, hands and feet. The margins for inaccurate manipulations are small.[9] It is a difficult surgery to learn with a complication rate of 5-20% in the first 200 cases performed by a trainee.[10] The average time required to learn to perform this procedure independently is 1 to 2 years. The number of complications decreases exponentially and the asymptote is reached only after 400-1000 cases.[11,12] In other words, patient safety is at risk when the operation is performed by doctors in training.

Andragogy, which refers to the learning strategies in adult, can help to explain why the current surgical training method is deficient and imposes a high risk to patients. Knowl M. made four assumptions in adult learning theory.[13]

(1) Adults need to know why they need to learn something. Phacoemulsification is the most commonly performed surgery in ophthalmology and when performed well, the visual outcome is excellent. Therefore all most all junior trainees are eager to learn this surgical skill. The eagerness to operate prevents most trainees from spending ample time learning the theory and obtaining essential surgical skills before making the first entry into a patient's eye. For instance, in making the corneal incision, the knowledge of the site, size and shape for the wound is important for intra-operative safety and visual outcome success. The skill in making a three-step incision requires precise instrument maneuvering under the microscope without direct hand-eye coordination. However, many trainees may not have a clear idea of the surgical plane and the required manual dexterity when they perform this procedure for the first few times.

(2) Adults need to learn experientially. When observing the skillful master surgeon operating, trainees can frequently underestimate how difficult a procedure can be. It is not uncommon for the trainees to realize the difficulty of making a three-step incision only when they sit in front of a

patient with a keratome in their hand looking down the microscope and struggle as the eye moves and distorts when they thrust the blade into the eye.

(3) Adults approach learning as problem solving. After the first nerve-wrecking experience making a corneal incision, trainees then start to search for solutions to avoid the same mistake from happening again. This process of improving surgical skills and knowledge only after encountering problems in live patients is repeated until the novice surgeon masters the skill. Each patient is therefore viewed as a learning opportunity because it is the only time for the trainees to find out what they do not know or cannot do. Consequently the learning curve of the trainees takes place mainly on live patients. This leads to the emphasis on how many patients the trainees have in their surgical logbook.

(4) Adults learn best when the topic is of immediate value. Trainees' interest in learning surgical skills is kept high if there is a constant opportunity to operate. Most trainees' dissatisfaction with their surgical training comes from the lack of opportunity to operate. Trainees may not see the value of reading or practicing surgical skills in the web lab if they do not have protected surgical time each week.

The current training method is also unsatisfactory from the trainers' point of view. The ultimate responsibility of patient care rests on the consultant. The consultant has to make sure the case is suitable for teaching purposes. If any complication arises during the surgery, the consultant has to rectify the problem and often it results in an unsatisfactory visual outcome. Even though training in a teaching hospital is accepted, it is still very upsetting for a patient to find out that the complication arises during teaching juniors. Junior doctors rotate periodically but the consultant has to provide long-term care for the patient. The consultant also may be involved in medico-legal issues even if they have not directly caused the complication.

Limitations Of Current Training

The current surgical training model has many other pitfalls apart from putting patients at risk in inexperienced hands. Many of these limitations result in frustration and lack of confidence for the trainee. The limitations of the current training enviroment include an unstructured curriculum, high finiancial cost, high human cost and time constraints.[14]

Unstructured Training

Currently, there is not a structured phacoemulsificaiton training curriculum for the trainees in the Irish College of Ophthalmologists (ICO) Basic Surgical Training Program (BST). Without a systematic instruction for the trainees, important concepts may be neglected. For example, trainees usually inherit the phacoemulsification machine setting from the trainer without understanding the importance of each parameter.

There are no guidelines in the ICO to ascertain if trainees have acquired necessary surgical competence before operating on a patient. Most trainees attend the Microsurgical Skill Course provided by the Royal College of Ophthalmologists in London as an introduction to opthalmic surgery. Despite the good syllabus in this course, there is no formal, objective, individual evaluation at the end to assess a trainee's readiness to start operating on patients. Attendance at this course is akin to readiness to operate. Subsequent surgical training is dependent on the trainee's consultant team. Since every consultant has his or her own teaching plan and a different spectrum of patients depending on the subspecialty, it is difficult to ensure that all the trainees get equal amounts of surgical training. The hard learned surgical skills may be lost if a trainee moves to a team with a lower surgical volume. Consequently, some rotations may be more favored by the trainees because of greater surgical opportunities.

The rotation of teams every 6 months also creates a lack of continuity for surgical training. Trainees may have to learn a different technique to conform with the trainers' expectations. It is hard for a trainee to keep up the momentum of progression when the learning experience is truncated. It may be more beneficial if the college was to take up the role of pre-training at a national level to ensure an uniform standard of surgical training for the trainees in the BST program.

Financial Costs

Financial factors can also contribute to training limitation as it is expensive to train surgical skills in the theatre. Trainees are being paid to observe and to practice unfamiliar surgical skills on patients. Surgical time is lengthened when a case is used for training. Costs are increased due to the use of disposable dressings and nursing and support staff overtime. In the United States, the annual national cost for training surgical residents of all specialties in the operating room is estimated to be $53 million US dollars.[15]

A potentially high cost for the provision of training is the medico-legal fee for surgical complications. According to the Irish State Claims Agency, the Clinical Indemnity Scheme report of 2007 states that the highest claim came from surgical specialties (50% of total claims).[16] Most of the claims were due to peri-operative incidents (22% of total claims).[17]

E-mail correspondence with a clinical risk adviser in the CIS revealed that there were a total of 6 claims related to cataract surgery from 2004-2008. Two cases had been settled for a total of €110,000. The remaining four cases are still under deliberation but are estimated to cost in the region of €600,000 in total if approved. The claims were taken for a number of reasons ranging from post-surgical infection, allegations of intra-operative pain awareness, allegations of failed cataract procedures and complications following cataract surgery. Due to protection of privacy, the surgeons involved in these cases have not been identified. Regardless of whether the surgeons involved were consultants or trainees, it is clear higher surgical error increases the chance of morbidity and medico-legal cost.

Human Costs

Initially trainees spend more time observing in the theatre rather than performing surgery. When a trainee is performing surgery the consultant has to supervise at all times to ensure the safety of the patient. The nurses and support staff have to remain on standby when the case takes longer than usual because of inexperienced trainees. If a complication occurs, additional time and resources are needed to rectify the problem. Training in theatre also reduces the number of cases that can be completed. With the long waiting time for elective catarat extraction surgery, hospitals are under pressure to run the theatre more effectively. In 2002, the National Treatment Purchase Fund (NTPF) was introduced to reduce the long waiting list for medical and surgical services. Over 135,000 patients have been treated under this scheme since its inception.[18] Ophthalmology is the highest surgical specialty that utilizes the NTPF to reduce patient numbers on the waiting list. In 2008 alone, 5240 ophthalmic patients, most of whom underwent cataract surgery, received NTPF treatment because they had been waiting to receive treatment longer than 3 months.[19]

Time Constraints

The duty of trainees in a theatre session is to ensure the patient is pre-operatively worked up properly and ready for surgery. Consequently, most of the theatre session is spent on admitting and consenting the patient. When the list is busy, a trainee may not have an opportunity to operate even if there is a suitable case for teaching. Theatre sessions are also reduced when either the consultant or the trainee is on annual leave.

The European Working Time Directive restricts doctors to a maximum of 48 hours working time per week. Furthermore, if a doctor is on call on-site for the night, it is mandatory for him/her to avail of compensatory rest the following day. This will greatly reduce the amount of theatre time available to a trainee and will therefore have a detrimental affect on training as the Halstedian training method relies on actual exposure to surgical cases.

In summary, the current surgical training method imposes an unacceptably high risk to patients if they are operated on by unskilled hands. At the same time, trainees do not receive adequate training because of a lack of a comprehensive, structured surgical training curriculum.

Medical Errors Are Too High

The current clinical climate has changed to demand greater safety for the patients. The need for better training is highlighted by the report "To Err is Human."[20] According to this report, the incidence of medical errors leading to patients' mortality and morbidity has reached an unacceptably high level. The authors estimated that as many as 44,000-90,000 people in the United States of America died of preventable medical errors per year. One of the key changes stipulated in this report is that better training for the health professionals is required.

The responsibility for better training does not rest with the health professionals alone. The hospital management and the overseeing professional body are also held accountable for medical errors that occur. In the famous Bristol Case, a cardiac surgeon who did not have prior training on neonatal arterial switch surgery performed this operation independently and resulted in nine consecutive deaths.[21] The surgeon was found guilty of professional misconduct for continuing to perform complex surgery despite the high mortality rate. At the same time, the chief executive officer of the Hospital Trust was found guilty of not acting on the high mortality rate in the unit. This court case cost the General Medical Council in the United Kingdom £2.2 million to carry out the investigation and £10 million in compensation.

Phacoemulsification is a complex procedure where the margin for error is very small. The conventional Halstedian method of surgical training exposes patients to a higher risk of complications when a trainee performs the surgery because the acquirement of operative skills mainly takes place directly on the patients. The trainee performs the surgery until difficulties or complications arise, and then the master surgeon takes over. Quite often, the trainees explore a new technique for the first time on a patient without any prior instruction or assessment to ensure the apprentice knows what to do, what to avoid and more importantly, the skills to carry out the procedure safely.

Healthcare professionals have a duty of care to the public. In response to heightened public awareness and expectation, the Accreditation Council for Graduate Medical Education (ACGME) in the United State of America established six general competencies for the resident education. The six core competencies are medical knowledge, patient care, practice-based learning, interpersonal and communication skill, professionalism and system-based practice.[22] In addition to these six core competencies, the American Board of Ophthalmologists added surgical competency to ensure the standard of surgical training is accountable to the public.[23]

Evaluation of Surgical Skills

The challenge in establishing surgical competency is to develop a method of evaluation that is effective and objective. The ACGME defines competency as the specific knowledge, skills, behaviors and attitudes and the appropriate educational experiences required of residents to complete the residency programs.[24] A competent surgeon is a person who not only makes the right decision for the situation encountered but also has the skill to carry out the procedure safely. Therefore neither making a wrong decision and performing the procedure completely nor making the right decision but being unable to perform the procedure safely is a sign of competency. Where as it is generally accepted that surgical knowledge could be objectively evaluated by a written test or viva voce, the surgical skill is hard to evaluate without subjectivity.

The currently employed surgical competency assessment methods are subjective evaluation, number of cases performed, wet-lab performance, video review of surgical cases and virtual reality simulation.[25] A single or a combination of the assessment methods may be used to evaluate the residents. Each method of assessment has limitations. The subjective evaluation is largely dependant on the trainer's personal preference. This method results in too wide a range of standard possible. The number of cases performed by residents may not reflect their actual surgical skills. It is influenced by the availability of cases and trainers willingness to teach. The wet-lab setting does not reproduce the real surgical environment and the response of human tissues to surgical manipulation. The video review method may result in case selection bias and failure to take the entire surgical environment into account. The virtual reality simulation is the only objective method but it is limited by the fidelity of the machine and there is yet no scientific evidence to prove its validity in assessing competence.

Efforts have been made to create a more objective method of assessment. Lee et al use the Dreyfus model of skill acquisition to define the scope of skills required for each stage of training in phacoemulsification.[26] The residents begin at as a novice and progress through beginner, advanced beginner, proficient and eventually become an expert. By clearly defining the skill required for each stage of the training, a training program and objectively structured assessment can be established. In this model, the residents are expected to reach the proficient stage by the end of their three years of training. A proficient surgeon according to this assessment method is a surgeon who can complete a case within 30 minutes. Cremers et al created a template for surgical competency evaluation called objective assessment of skills in intraocular surgery (OASIS).[27] This evaluation method takes into account the preoperative information, intraoperative information and the postoperative results for each case. The contribution from the trainer is mainly in the intraoperative section. The advantage of this template is that the difficulty of each case and the progression of the surgical skill acquisition as well as the visual outcome can be evaluated objectively.

All the current validated assessment methods are designed to evaluate the surgical skill competency of the trainees after completion of residency training.[28,29,30] While it is vital to ensure the trained surgeons are indeed competent before unleashing them to perform surgery independently, it is equally important to ensure that the novices are pre-trained to a proficient level before they start operating on patients under supervision. There is yet no guideline or objectively validated method to assess the readiness of a trainee to start operating on a patient.

There is a substantial amount of skills that can be learned outside the operating theatre. The Halstedian motto of 'see one and do one' cannot apply in phacoemulsification because while looking into the microscope, the trainees can see what happens but they cannot see how it happens because the action of the hands and feet are outside the view of the microscope. Training models have been used for training but most of them do not have a built-in assessment function. Therefore, the effect of the training cannot be objectively evaluated.

The University of Iowa Ophthalmology Department developed a wet lab based curriculum which included assessment, however the proficiency level was not defined.[26] Therefore the curriculum is based on attendance and theoretical knowledge but not on proficiency in skills. The complexity and legal responsibility of performing surgery surpasses that of driving a car. Yet, there is no accepted testing standard nor a requirement for the trainees to obtain an 'operating permit' before they start to operate. Better training and objective competency based assessment are the key strategies in attaining the goal of reduced medical errors.[31] Risk in surgery for patients can be reduced if there is a training curriculum with a pre-determined proficiency level and objective assessment to ensure the readiness of the trainee to start operating safely. A structured pre-training curriculum based on achievement instead of attendance is urgently required to ensure each trainee acquires sufficient knowledge and surgical skill before performing surgery for the first time.

Learning Theories

A better understanding of the learning process and skill acquisition had led surgical trainers to re-evaluate the effectiveness and patient safety in the traditional way of teaching surgery.

Peyton's Learning Cycle

In Peyton's learning theory,[32] novice surgeons start at an unconciously incompetent stage where they do not even know what they do not know. As they become exposed to a situation, the awareness makes them become conscious of their incompetency. Through repeated trials they eventually become consciously competent. In learning cataract surgery under the Hastedian model, trainees often only become aware of what they are incapable of when they are actually operating on patients. Then the mentality is that they should repeat the same procedure on as many patients as they can in order to become comptent. As a result, their learning curve depends on the number of patients available.

In a preliminary survey based on Maslow's hierachy of need in the learning enviroment, the trainees are satisfied with their cataract training environment, when they feel supported and feel part of a group. Nevertheless, the trainees gave the lowest score to the lack of opportunity to master skills. This reflects the disappointment in lack of patient exposure. Despite many trainees' eagerness to operate on patients, a survey in this study also revealed that only 1 out of 25 practiced skills weekly in the wet lab, while the rest either never or very seldomly practiced in the wet lab. The lack of formal ICO guidelines and lack of demand by consultant trainers are the main reasons why trainees do not practice in the wet lab despite their wish to learn cataract surgery. This dependence on patient flow for learning surgical skills not only places patients at risk but also is becoming a problem when the working hours of the doctors are reduced under the European Working Time Directive and suitable patients are being treated under the National Treatment Purchase Fund.

Fitts and Posner's Three-Stage Theory of Motor Skill Acquisition

Fitts and Posner's Three-stage Theory of Motor Skill Acquisition effectively identified the process of learning surgical skills.[33] These three stages in chronological sequence are the cognitive stage, the integrative stage and the autonomous stage. According to this theory, the motor skill learning process begins with understanding of the task through explanation and demonstration. The trainee then attempts to comprehend and perform the task. The initial attempts are usually erratic and in distinct steps. By deliberate practice and feedback from analyzing the result, the performance becomes more fluid with fewer interruptions. Eventually, the trainee can perform the task with speed, efficiency and with precision. Thus the performance becomes automated requiring little cognitive input. The extra mental capacity can be used to focus on refining performance.

Applying this theory to phacoemulsification training, the progression of learning from novice to competent is as follows:

Cognitive stages

- Anatomy, physiology, and biochemistry of the eye
- Diagnosis of cataract and risk associations
- Types and functions of surgical instruments
- Sequence of the surgical procedure
- Principle for safe and effective performance in each step
- Potential complications and how to avoid mistakes

Integrative stage – Performed with supervision

- Hand-eye co-ordination under the microscope
- Instrument handling and maneuver
- Fulcrum effect at the corneal entry sites
- Foot control for microscope and phacoemulsification machine
- Phacodynamics and machine settings
- Performing each step successfully

Autonomous stage – Performed without supervision

- Able to complete a full case consistently
- Operate on cataract associated with higher risk factors

It can be clearly seen that the cognitive and integrative stage can be largely accomplished without involving any patient. Learning to operate on patients increases the risk of complications because a novice trainee has to pay attention to too many things when learning a new procedure. The attentional capacity is divided between psychomotor performance, depth & spatial judgement, operative judgment, decision making, comprehending instructions, and gaining additional knowlege.[34] Most complications happen when trainees fail to recognize an imminent danger either due to lack of knowledge or lack of the mental capacity to identify it. The method to increase the mental capacity is to pre-train knowledge and basic psychomotor skills in a controlled environment first. For example, the use of microscope, instrument handling, and foot pedal control of the phacoemulsification machine can be learned before starting to operate on patients. In this way, a pre-trained novice can pay more attention to the actual surgery and thus reduce the complication rate. The pre-training curriculum should be proficiency based to ensure that the trainee has an accepted level of competency before operating on a real patient.

The Role of Virtual Reality Simulation In Surgical Training

The current advance in Virtual Reality (VR) simulator technology may be used to transform the learning theories into practice. Virtual Reality simulator training has been used in training students in many highly skilled professions such as aviation.[35] In 2004, the Food and Drug Adminstration in the United States of America voted to make Virtual Reality simulation of carotid stent placement an important component of training and thus set the milestone of VR use in medical professions.[36] A Virtual Reality simulator training curriculum has several advantages. It can be programmed to be broad-based and subject the trainees to systematic exposure to a wide range of possible clinical problems.[37] It is available at any time to practice difficult procedures repeatedly and consequently, it could shorten the learning curve without posing a risk to patients.[38] It can also lower the educational cost by reducing the manpower and theatre time required for training.[39]

The Virtual Reality simulator is an invaluable training tool because it provides a platform for the trainers to teach trainees knowledge and skill by simulating various surgical scenarios. In the operating room, there is seldom sufficienty time to teach on the spot. However, in a simulator training session, there is ample amount of time for trainees to explore different approaches and find what suits them best. If they struggle with one particular task, the trainer can find out what they think and listen to their reasons for performing a task in a particular way. The trainer can then help them to identify the problem and offer an alternative solution. The trainer can observe first and encourage them to ask questions. Trainees learn better when they are given choices and reasons for performing a task. Learning a new skill can be frustrating. It is important to show that the skills they acquire from the simulator may help them in real life at a later stage. Knowing what is useful to them is a strong motivation for overcoming the challenge.

Satava proposed using virtual reality simulator as a training tool for minimally invasive surgery in 1993.[40] While many surgical specialties have embraced this idea, acceptance for this method of training in ophthalmology has been slow.[41] A reason for this is the lack of knowledge of how to effectively apply simulation to a surgical skill-training program.

Gallagher et al proposed a template for developing a Proficiency Based Progression (PBP) curriculum in the following sequence:[36]

1. Didactic teaching of relevant knowledge
2. Instruction on the steps of the task or procedure
3. Defining and illustrating common errors
4. Test of all previous didactic information to ensure the student understands all of the cognitive skills before going to the technical skill training
5. Technical skills training on the simulator
6. Provide immediate (proximate) feedback when an error occurs
7. Provide summative (terminal) feedback at the completion of a trial
8. Reiterate the skills training (repeated trials)
9. Exit of a training program based on achieving a predetermined proficiency level

The first four steps are for gaining knowledge whereas the next four steps are for acquisition of skills. The last step is the hallmark of a proficiency based training curriculum. Unlike many surgical skill-training courses where attendance is the only criteria for getting a certification, the PBP curriculum demands the trainee to achieve the predetermined skill level as the end point of the training.

EYESi Simulator Review

Virtual reality simulator training is avalaible in retina laser photocoagulation,[42] catarct extraction by phacoemulsification,[43] and vitreoretinal surgery.[44] Currently, two high fidelity virtual reality simulators for training of phacoemulsification are commercially available: EYESi (VRMagic, Mannheim, Germany)[45] and Phaco Vision (Melerit Medical, Linkoping, Sweden).[46]

The EYESi cataract simulator has been shown to demonstrate construct validity for instrument training modules.[47] It also has been proven to be effective in improving wet lab performance of capsulorrhexis by a radomized, controlled trial.[48]

The Irish College of Ophthalmologists possesses an EYESi vitreoretinal and cataract simulator. The trainees in the BST program are required to attend simulator training sessions. However, there is not yet a consensus on how much time and what score the trainees should achieve in the training.

Phacoemulsification is ideal for simulator training because this procedure is essentially dependent on visual feedbacks and the tactile feedback is almost absent. Hand-eye coordination may be trained with virtual reality applications until a good level of psychomotor skill is acquired. The entire procedure can be broken down into small steps and practiced until an appropriate proficiency level is reached. With its built-in metrics, the skill level can be quantitatively and objectively measured and can be used to monitor trainees' progression.

Drawing from the experiences of other surgical specialties, the effectiveness of virtual reality simulation as a training tool in surgery is well established.[49,50] However, despite all the potential benefits a VR simulator can offer, the scientific evidence for its effectiveness in cataract surgery training is scarce. Mahr et al showed that the EYESi cataract training simulator can differentiate the ability of different skill levels of surgeons in just two skill training modules.[51] The attending surgeons not only performed better but were also more consistent in replicating good performance when compared to the residents. However, this study only has a small cohort comparing 12 residents with just 3 attending surgeons. Feudner et al showed that training with EYESi simulator improved wet-lab performance of capsulorrhexis.[52] In this study, all participants received a didactic lecture to ensure they understood what was required of them. The training group had to train on the simulator until a pre-set proficiency level was reached. The control group received no simulator training. The flap of the capsule of a pig eye was created by an experienced surgeon. The participants continued the flap in a continous curvilinear fashion until the rhexis was complete. The procedure was videotaped and scored by two independent obervers who are not aware of the participants' training status. The results showed that training on simulator improved the size, site and shape of the rhexis as well as tissue protection.

This scientific evidence, although limited in quantity, showed the great potential of virtual reality training for cataract surgery. The question the surgical training body faces is how to effectively incoorporate the simulator into the current training curriculum. First of all, there is a lack of knowledge on how to best utilize the simulator as a training tool. Currently, there is no agreed proficiency level on the simulator that a trainee should attain. Secondly, there is no information on how long it will take to train a trainee to the desired proficiency level. Consequently, the training body cannot allocate appropriate financial and human resources for the simulator training.

OBJECTIVES

The aim of this project is to design and validate a proficiency-based progression curriculum for phacoemulsification training utilizing virtual simulator technology. To achieve this purpose, the following study plans are proposed:

1) To establish construct and face validity for EYESi cataract simulator
2) To set the proficiency level for simulator training.
3) To design an online based didactic lecture
4) To design a comprehensive proficiency based training curriculum for cataract surgical training based on the EYESi simulator.
5) To demonstrate acquisition of pertinent surgical skills by training on the EYESi simulator.

The importance of showing construct validity on the EYESi simulator is so that the score attained by the expert group can form the basis for setting the proficiency level for the trainees. The difference in scores between these two groups can be assumed to be due to the difference in the skill levels for cataract surgery. Therefore, by improving their score on the simulator, trainees would gain relevant skills needed for cataract surgery during this process. A proficiency level is the target score a trainee has to achieve in order to demonstrate acquistion of pertinent skills.

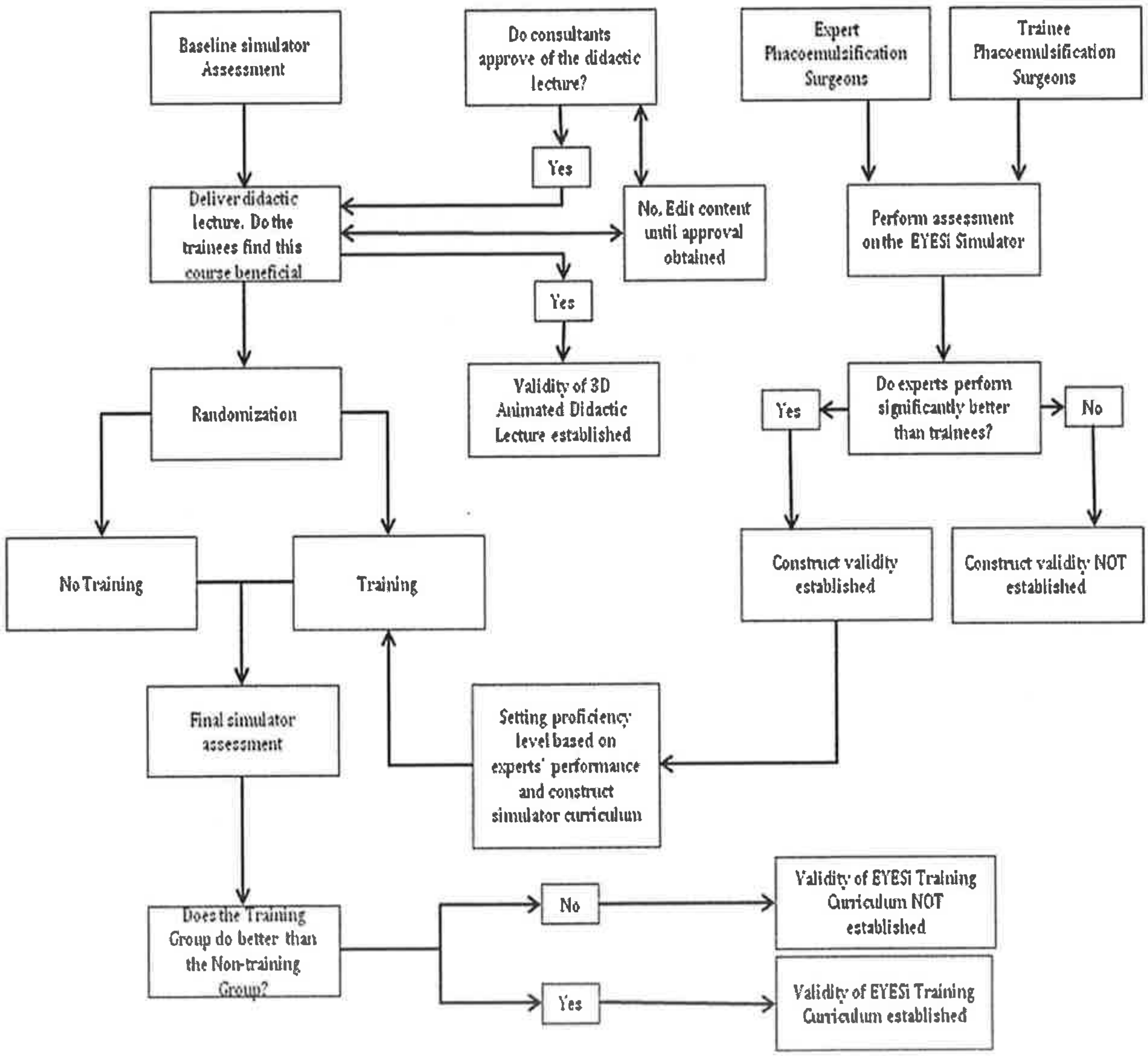
The didactice curriculum is to ensure the trainees understand the principles of cataract pathophysiology, phacoemulsification surgical techinques and potential complications. The use of multimedia technology will help to consolidate abstract surgical concepts into fundamental surgical guiding principles.

The simulator training curriculum, on the other hand, is the framework that guides the trainees in reaching proficiency in surgical skills. The curriculum can be designed in various ways to reach the same end point. For example, a curriculum can require the trainee to begin from level 1 and work towards a higher level or just repeat the higher level until it is passed. A good curriculum should be achievable, reproducible and maintain the trainees interest throughout the course. It should also be thorough and meticulous in order to ensure the quality of skill acquisition. The effectiveness of this comprehensive training program for phacoemulsification is evaluated by comparing the level of skill acquisition of the trained and non-trained group in a prospective randomized controlled study.

The outcome of this study is to create a valid didactic and skill acquisition curriculum for better training of our future ophthalmic surgeons. Better training is the key aspect of improving our current standard of care for patients. It is envisaged that this study will support a new paradigm of surgical training where most of the learning curve for gaining fundamental surgical skills will be done in a controlled, supervised environment using the latest computer technology without a risk to patients. Consequently, the errors and complication rates currently experienced by the trainees can be significantly reduced.

MATERIALS AND METHODS

Overall Study Plan



SECTION I

Validating EYESi Simulator As An Assessment And Training Tool

Objective: To establish construct validity and face validity of EYESi simulator

Method:

Construct validity refers to the strength of the instrument to measure what it intends to measure. The aim is to find out can the metrics in the EYESi simulator set apart experienced from inexperienced surgeons. In order to use EYESi simulator as a training tool, it should be able to differentiate operators with different surgical skill levels using its metrics. The difference in the score attained can be used as a training target. By training to the level of the 'expert' surgeon, the novice surgeon is likely to gain useful surgical skills from the simulator. Face validity refers to how much the simulator appears to be a useful training tool based on the participants' opinion. This is achieved by requesting the participants to complete a survey after partaking in the assessment.

Fifteen experts and 18 trainees in cataract surgery were recruited for this study. The inclusion criteria for the expert group was having performed more than 500 cases of phacoemulsification independently. This group included consultant surgeons and the current Specialist Registrars (SpR). The aim was to recruit expert surgeons with a varying range of experience so that the proficiency level represents the surgical ability of the generally accepted group rather than the elite range. Training surgeons were junior doctors currently in a training post who have performed less than 80 cases of phacoemulsification. The surgical training background information was gathered from the trainees (Appendix II –Survey 1)

EYESi simulator technical information:

Manufacturer: VRMagic GmbH, Augustaanlage 32, 68165 Mannheim, Germany. Website: www.Vrmagic.com

Hardware: VRMagic Cataract Surgery Head and Anterior Segment Instrument Set

Software: Release Version 2.4

Modules tested:

EYESi Version 2.4 has five training modules and two surgical simulation modules. Each module has a varying level of difficulties. As a training program incorporating simulator, the level of difficulty chosen was aimed to represent the skills and knowledge required in order to perform on the type of cataract appropriate for trainees to do in the operating theatre. Therefore, the level chosen should not be too easy or too difficult for the skills expected of the trainees. The modules and level of difficulty chosen for the assessment were the followings:

Modules	Levels Available	Level Chosen For Assessment
Cataract Navigation Training	3	3
Cataract Anti-tremor Training	7	3 or 4 *They are the same task but differ only in the direction of motion
Cataract Forceps Training	4	4
Capsulorrhexis	10	8
Cataract Bimanual Training	5	4
Cataract Crack & Chopping Training	8	6
Phaco Divide and Conquer	6	6

Instructions to each participant:

1.) Introduction to the simulator:

i. The simulator platform table height and the chair height can be adjusted to suit individual need.

ii. The microsope eyepiece can be adjusted for inter-pupillary distance and refractive error for each eye. This was done prior to starting the simulation. The participant should be able to see stereo images.

iii. Two handheld instruments. The red tip instrument has a straight tip. The yellow tip instrument has an angled tip. These tips are round ended but have orientation sensors. When the yellow tip simulates the forceps, second instrument, or cystotome, it has to be entered at an angle to simulate avoiding the damage of corneal stroma at the entry site. When the red tip instrument simulates phaco probe, it can be rotated so that the bevel faces up.

iv. The position of the head can be arranged for frontal or temporal approach at the participant's preference. Change the setting on the computer to get the correct visual orientation.

v. The artificial eye in the cataract module head has several entry ports. The participant is to enter into the eye at the axis they are accustomed to in real surgery. Avoid touching the artificial eye with fingers.

vi. Microscope foot pedal can control focusing, zooming and shifting in the X-Y plane. There are four other buttons on the foot pedal for other functions and these should be avoided.

vii. Phacoemulsification foot control is linear, not dual-linear. It has multiple functions depending on the modules. For forceps, press down to close the tips and lift to open the tips. For viscoelastic syringe, press down to inject. For phacoemuslification, slightly press down to activate irrigation. Press further down to activate aspiration and down more to activate ultrasonic energy.

viii. Phaco machine parameter setting. The program has a default setting for bottle height, maximum vacuum and flow rate and maximum ultrasonic energy. The participant can chose to use vaccum pump or flow pump for aspiration. The ultrasonic energy can also be set for continuous or pulsed mode.

ix. Ensure that the participant is comfortable and is ready to proceed.

2.) At the beginning of every module tested, the participant will have the opportunity to become familiarized with the task to be performed by practicing on the easiest level (ie Level 1) once. Verbal instructions for each module and the main criteria that define the score will be given prior to the trial. Questions regarding the task will be answered. The score will be shown for this trial only so the participants know how the simulator grades their perfomance.

3.) When the participant is ready to proceed to the formal assessment for that module, he or she will repeat the level chosen for assessment 5 times consecutively. At this stage, the score will not be shown to the participant. This is to avoid the participants changing their surgical styles only to suit the computer in order to get a higher score.

4.) The same process will be repeated for each module until each is finished.

5.) After completion of the assessment, each participant answers a survey questionnaire giving feedback on the simulator experience.

Instructions given to the participant at the beginning of each module:

Module 1: Cataract Navigation Level 3

Task Instructions:

1.) Move the tip of the needle into the red sphere

2.) Hold the tip within the sphere until it turns green

3.) Once a red sphere turns green, you may proceed to the next red sphere

4.) The task is complete when all red spheres turn green.

The main criteria that define your score are:

1.) Time

2.) Remaining objects

3.) Injured lens & cornea area

4.) Accuracy of targeting

5.) Odometer

Module 2: Cataract Anti-Tremor Training

(Level 3 or 4 depending on the direction of capsulorrhexis)

Task Instructions:

1.) Place the tip of the instrument in the centre of the blue sphere.

2.) Move the sphere along the path marked out by the blue line.

3.) When finished the actual trajectory of the instrument tip is displayed. A green line indicates the trail is within the tolerance range. A red line indicated the trail is outside the tolerance range.

4.) Avoid touching the cornea or lens

The main criteria that define your score are:

1.) Time

2.) Tremor

3.) Injured cornea & lens area

4.) Accuracy of targeting

Module 3: Cataract Forceps Training Level 4

Task Instructions:

1.) Use the foot pedal to open and close the forceps

2.) Enter the eye with the hand instrument turn sideways with forceps closed

3.) Once inside the eye, turn the hand instrument back to the upright position

4.) Grab an object and place it inside the central buscket. Repeat the same procedure until all the objects are inside the buscket.

5.) Avoid touching the cornea or lens

6.) Avoid tilting the eye

7.) The bar on the right side of the microscopic view indicates the distance of the forceps to the cornea and lens

The main criteria that define your score are:

1.) Time

2.) Odometer

3.) Injured lens & cornea area

4.) Stress on incision

Module 4: Cataract Bimanual Training Level 4

Task Instructions:

1.) Place the tip of each instrument into the spheres on either end of the rod simultaneously

2.) Hold the tips of the instruments inside the spheres until they turn green

3.) Once the spheres change their color you can proceed to the next sphere

The main criteria that define your score are:

1.) Time

2.) Odometer

3.) Injured lens & cornea area

4.) Tremor

Module 5: Cataract Cracking & Chopping Training Level 6

Task Instructions:

1.) Place the tip of each instrument into the sphere at either end of the rod

2.) Slide the spheres outward until the end of the rod is reached

The Main Criteria that define your score are:

1.) Time

2.) Instrument tip slips out of the sphere

3.) Tremor

4.) Injured lens & cornea area

Module 6: Capsulorrhexis Level 6

Task Instructions:

1.) Inject the viscoelastic with the foot pedal

2.) Create a flap in the capsule with cystotome

3.) Use forceps to tear a continuous curvilinear capsulorrhexis

4.) Remove the capsular membrane with the forceps

The Main Criteria that define your score are:

1.) Time

2.) Centering of rhexis

3.) Roundness of rhexis

4.) Maximum radial extension

5.) Local irregularity

6.) Injured cornea area

7.) Stress on incision

Module 7: Phaco Divide and Conquer Level 6

Task Instructions:

1.) Explain the setting of the phacoemulsification machine parameters and the use of foot pedal

2.) Enter the straight instrument first. The angled instrument has to enter the port horizontally.

3.) Groove and crack the lens into several pieces.

4.) Advance to mode 2 of the program with the foot switch.

5.) Remove the lens materials without damaging the capsule

The Main Criteria that define your score are:

1.) Anterior capsular torn

2.) Posterior capsular torn

3.) Ultrasound energy leakage

4.) Ultrasound energy usage

5.) Tissue damage

SECTION II

Setting Proficiency Level And Designing Proficiency Based Skill Acquisition Curriculum With EYESi Simulator

Objective: To design a structured, proficiency based training curriculum for EYESi simulator.

Method:

The proficiency level is determined by taking the best three out of five of each expert's performance. This is an attempt to eliminate poor performance due to lack of familiarity with the simulator. To further raise the standard, only scores of the top 10 out of 15 participants were included.

The initial assessment was done on EYESi Cataract Module Version 2.4. Meanwhile the improved Version 2.5 became available in May 2009. The two versions were tried and the new version gives a more realistic simulation. Therefore, from training point of view, it was better to train the trainees on the newer version. The same score value obtained from the Version 2.4 was used for the proficiency level in Version 2.5 without adjustment, despite the fact that the second version has different scoring system. To assess the appropriateness of the proficiency level, each module was tested to ensure that the target scores were realistic and achievable.

The EYESi simulator curriculum in this study is designed with the following principles: distributed, structured and deliberate practice with immediate feedback.[53] The endpoint of the training is the proficiency level set based on the expert group's performance.

Distributed practice is a learning method where the training is spread over time rather than concentrated in a few days. The curriculum in this study was designed with two main categories in mind, the Capsulorrhexis Curriculum and the Phacoemulsification Curriculum. There are 41 tasks in total, which were evenly distributed in 10 courses.

This curriculum is structured with clearly defined learning objectives. The aim is to reach the proficiency score in each task. To incorporate deliberate practice, a gate of 3 consistent performances is stipulated.[54] Trainees need to attain target score on three consecutive occasions in order to move on to the next task. This is to ensure that the trainee achieved the target score with true skill, and not by chance. If the score fell below the proficiency level before reaching a third consecutive attempt, the trainee had to start again. Thus, reproducible performance was an important quality in this training curriculum.

The number of attempts is not a determining factor. A trainee can try as many times as needed to achieve proficiency. The curriculum is designed to incorporate the individual skill components to gradually build up to performing complete surgical tasks, a learning method called chunking.[55] For each training module the trainees started with the lowest level and advanced to the next level only if the target score was reached.

Capsulorrhexis Curriculum

In this curriculum, Navigation (3 levels), Forceps (4 levels) and Anti-Tremor (4 levels) are necessary skill components that a trainee has to master before they proceed to the Capsulorrhexis module. In order to complete capsulorrhexis successfully, the surgeon has to create a flap with an edge for the forceps to grab. Once the forceps grab on the edge of the flap, the surgeon needs to advance the tear in a continuous circumlinear fashion while grabbing and re-grabbing as often as necessary with a steady hand. The Navigation module aims to train steady hand movement of the angled instrument with emphasis on economy of movement and maintenance of red reflex. The Forceps module trains for opening and closing the forceps at various points along a circular pathway. In this task, the trainees have to use a foot pedal to control the opening and closing of the forceps. VRMagic has released a hand-controlled forceps to approximate the tactile feedback of a capsulorrhexis forceps. This instrument is not available to the Irish College of Ophthalmologists due to the financial cost. The Anti-Tremor module aims to train the trainees to develop a steady and smooth circular movement of the instrument. This is an important practice because the shape and size of the capsulorrhexis depend on this movement.

There are 10 levels available in the EYESi simulator for capsulorrhexis. Only the first 8 levels are included in the curriculum because level 9 and 10 involve dealing with complications, which is beyond the scope of basic surgical training. Level 1 begins with a flap created in a clockwise direction and a black circular guideline. The trainees have to advance the tear along the black line until the capsulorrhexis is complete. Level 2 is the same as level 1 except that the flap is created in a counter-clockwise direction. From Level 3 onward, the trainees have to first inject viscoelastic device to deepen the anterior chamber and then create the flap with a cystotome. At this stage, the trainee can decide which direction they want to commence the capsulorrhexis. The tendency of the capsule to tear increases gradually. Level 3 and 4 are low, level 5 and 6 are medium and level 7 and 8 are high. They also differ in the presence or absence of a black circular guideline. Level 3, 5 and 7 have guideline and level 4, 6 and 8 have not. The tendency to tear refers to how sensitively the capsular tear responded to the movement of the instrument. The higher the tendency to tear the less tolerant the capsular tear is to jerky movement of the instrument. Therefore, as the trainees reach the higher level, the demand for steady movement increases. This method of training from easy to difficult levels is called shaping. The presence of a circular guideline makes the task easier because the trainees do not have to decide the path.

Phacoemulsification Curriculum

In the Phacoemulsification Curriculum, a similar training methodology to the Capsulorrhexis Curriculum is employed. The individual skill component modules are Bi-Manual Training, Cracking and Chopping Training and Phaco Training. All these modules require two-hand operation. The Bi-Manual Training is similar to the Navigation Training in which steady control with economy of movement and maintenance of red reflex are the important parameters.

The Cracking and Chopping Module aims to train bi-manual dexterity in moving the tips of the two instruments in a straight line. Successful cracking in real surgery requires the use of instrument tips to exert vector force on two surfaces of the groove in linear fashion to maximize the effectiveness of cracking. In this module, there are two barbell shaped objects in the anterior chamber. Each barbell consists of a rod with sphere at two ends. The trainee has to engage both spheres at the end of the barbell simultaneously and move them either toward or away from the center for training on chopping and cracking, respectively.

The Phaco Training module is a vital component of this curriculum. In this module, trainees have to understand the factors that determine phacodynamics and how to set various phaco machine parameters. The trainees also have to learn to control the irrigation, aspiration and ultrasonic energy activation with the foot pedal. There are 3 levels in this module with increasing hardness of lenticular substance. Therefore the trainees have to be able to control the level of aspiration and the amount of ultrasonic energy usage according to the lens hardness. The EYESi simulator uses a linear control foot pedal as opposed the more popular dual linear control pedal used in most eye theatre in Ireland.

The Phaco Divide and Conquer Module is the procedural task for removing lens material. In Level 1, only one quadrant is left to remove. The trainees have to advance the phaco machine setting to segment removal mode before inserting the instrument into the eye. The instrument with a straight tip that simulates the phaco probe is inserted into the eye first with the foot activating the irrigation. Then the angle tip acting as the second instrument has to be entered into the eye sideways just like in a real surgery. The trainee then advances the phaco tip so that it is placed against the lens fragment. Meanwhile, the vacuum needs to be built up by using the foot pedal control until a vacuum seal is created at the phaco tip by occluding it with the lens fragment. Once the trainee has a good grip on the lens fragment, he or she then brings the fragment to the middle of the capsular bag at the iris plane before emulsifying the fragment with higher ultrasonic energy. The trainee needs to pay particular attention not to use excessive energy and to avoid post occlusion surge. Once the fragments are removed, the task is completed. The second instrument is removed first and then the phaco tip. In Level 2, there are four cracked lens fragment instead of one. The procedure is the same from removing each individual fragment. In this level, the trainee has to position the fragment to be removed by rotating it with the second instrument.

Level 3 and 4 provide training for cracking. In level 3, there is one grove already in the lens and it needs to be cracked into two hemispheres. In level 4, there are two groves perpendicular to each other, and the lens needs to be cracked into four quadrants. Level 5 and 6 are the complete phaco divide and conquer modules. At the beginning of the task the capsulorrhexis and hydrodissection have already been completed. The trainees are expected to make two grooves that are perpendicular to each other, crack the lens into four quadrants, then change the phaco machine setting to segment removal and remove each quadrant sequentially with phacoemulsification. Forty percent of the mark is given to cracking the lens material into four quadrants successfully. The remaining sixty percent of the mark is given to removing the lens material completely. Surgical complications, ineffective use of phaco machine and poor instrument handling will result in a reduction of marks. The surgical complications includes anterior and posterior capsular tear. Ineffective use of the phaco machine such as excessive ultrasonic energy leakage and usage can result in failure despite completing the task successfully. Poor instrument handling including loss of red reflex and damage to intraocular tissues can also result in failure to achieve the target score.

SECTION III

Designing A Didactic Lecture For Knowledge Acquisition In Cataract Surgery

Objective: To validate a comprehensive didactic lecture containing 3D animation for phacoemulsification surgery.

Challenges in Designing A Diadactic Curriculum

Phacoemulsification is a complex operation of the intricate ocular tissues that requires a high power microscope for viewing. Trainees can observe the surgery by viewing through an assistant eyepiece. However, while the trainees can see what is being done, he or she will miss the opportunity to observe how it is being done. Cataract surgery is a fingertip surgery where most of the movement for the instrument is controlled by the fingers. The hands and fingers of the surgeon are usually outside the surgical field of the microscope. Trainees cannot look into the microscope and watch the surgeon's finger movements at the same time. Furthermore, the main control of phacodynamics is by the foot, which is hidden underneath the table. Again, the trainee can see the effect of the foot pedal control but does not know how it was being done.

In designing a didactic curriculum for minimal invasive surgical procedure like phacoemulsification, the challenge is to enable the trainees to visualize what is happening with the hand, foot and machine dynamic at the same time. Textbooks use words and diagrams to describe the event. The reading is usually lengthy and the reader has to mentally reconstruct the actual procedure, which can be quite abstract. On the other hand, video recordings can show the procedural sequence very effectively. The disadvantage again is the viewer cannot see the surgeon's hand and foot movement. In other words, the viewer can see what happened but does not know how it happened.

Method:

Microsoft Office PowerPoint (Version 2007) was used to create a lecture for phacoemulsification. Images of surgeons and patients in theatre were taken with a digital camera. Verbal permission was obtained from the participating surgeons and patients. Three-dimensional animated slides were created using PowerPoint software version 2007 Windows System.

Syllabus for the didactic lecture:

A. Anatomy
    a. Lens
    b. Anterior chamber
B. Instruments
    a. Microscopes
    b. Foot pedal controls
    c. Handheld instruments
C. Positioning
    a. Patient's position
    b. Surgeon's posture
D. Sterilization and draping

E. Corneal incisions

    a. Architecture of wound construction

    b. Location of incision

F. Viscoelastic injection

    a. Types of Ophthalmic Viscosurgical Device (OVD)

    b. Purpose of OVD

G. Capsulorrhexis

    a. Physics of tear

    b. Instrument mechanics and handling

    c. Initiation and completion of rhexis

H. Hydrodissection

    a. Instrument placement

    b. Goal of hydrodissection

I. Phacoemulsification

    a. Phacodynamics and parameter settings

    b. Instrument mechanics and handling

    c. Sculpting

    d. Cracking

    e. Segment removal

    f. Avoiding complications

J. Irrigation and aspiration

    a. Machine setting

    b. Foot pedal control

K. Intraocular lens insertion
    a. Structure of an IOL
    b. A-scan
    c. Location of insertion
L. Viscoelastic removal
    a. Complication of OVD retention
M. Corneal wound closure
    a. Stromal hydration
    b. Suture
N. Learning tips
    a. Deliberate practice
    b. Video recording
    c. Wet lab and simulator practice

A structured didactic lecture with 3D animated PowerPoint presentation on phacoemulsification was presented to a group of ophthalmic consultants (n=5). The content was deemed appropriate and met the standard for Irish trainees. Ophthalmic surgical trainees (n=24) attended the lecture in the form of an oral presentation with slide projector. The training session lasted two and half hours. At the end of the lecture, each trainee answered two questionnaires to evaluate the benefit of this lecture material (Appendix II – Survey 2 and 3).

SECTION IV

EYESi Simulator Training For Skill Acquisition In Cataract Surgery

Objective: To validate the content of the structured proficiency based progression curriculum by comparing the effect of training in the trained and non-trained groups.

Method: Randomized control trial for effectiveness of the skill acquisition in training vs. non-training group

A structured skill acquisition curriculum on the EYESi simulator based on the proficiency level set by the expert group was constructed. Ophthalmic trainees (n=20) in the Irish College of Ophthalmologists Basic Surgical Training Scheme participated in this study. Ethics approval for this study was obtained from the Research Ethics Committee of the Royal College of Surgeons in Ireland.

The mixed level of surgical experience of the trainees recruited makes simple randomization for the treatment unreliable because the end result may be influenced by the surgical skills they have acquired already. In order to achieve a balanced baseline surgical experience levels between the training and non-training groups, the participants were firstly stratified based on the number of surgical phacoemulsification they have done to date. Sixteen participants had performed less than 20 cases of phacoemulsification and four participants had performed between 40 to 70 cases of phacoemulsification. In each stratum, the participants were randomly assigned for training or non-training using a randomization table. The advantage of this method of randomization is to keep variability of participants within strata as small as possible in order to avoid an imbalance between the training and non-training group.[56] Every participant underwent a baseline simulator assessment. The participants randomized for the training group received one to one training by Dr Princeton Lee on the simulator until the proficiency level was reached. The control group did not receive any training on the simulator apart from what they were entitled to with the surgical tutor as require by the ICO. After the training period, everyone underwent the same assessment protocol as the baseline assessment. Ten of the trainees had the baseline assessment in software version 2.4 and ten trainees in version 2.5. All twenty trainees were assessed in version 2.5 in the final assessment.

The simulator training took place in the ICO office, which was quiet and had a very low level of distraction. Most training sessions were carried out in the evenings or weekends because all of the trainees were in full time employment in a hospital. The length of each training session was dependent on the trainee's availability and the ability to concentrate. There was no restriction on how soon the trainees could book their next session. The end point of a training period was when a trainee completed all of the modules to a desired proficiency level. After the completion of the training program, the trainees answered two surveys, one for the usefulness of the simulator (Appendix II – Survey 4) and one for feedback on the trainer (Appendix II – Survey 5).

The post training (second) assessment took place within 3 weeks of the last training session. The participants in the non-training group also underwent the second assessment at similar period to the training group. In the second assessment session, the participant received full instructions on how to perform each module. This differed from the baseline assessment in that three instead of five trials were done for each modules.

After the simulator assessment, each participant continued with the aptitude test. The purpose of this section was to investigate the relationship between the participant's learning curve and their innate cognitive and spatial ability. This was carried out to search for individual characteristics that may be used to predict learning curve.

The aptitude test was a pen and paper test with three different components: card rotation, cube comparison and map planning.[57] The instructions were given as per the publisher's standard operational guidelines. In the Card Rotation Test, the participant was shown an abstract figure and was asked to identify which of six other drawings represented the model in two-dimensional space. There were twenty test items, with a time limit of 3 minutes. In the Cube Comparison Test, two drawings of a cube are presented; the study participant is asked to indicate whether the two drawings are of the same cube rotated in three- dimensional space. The Cube Comparison test has two parts, each with fifteen items, and a time limit of three minutes. In the Map Planning Test, a checkerboard map with different destinations is given to the participant. The participant has to find the shortest route to each destination with stipulated rules. This test has two parts each with 3 minutes. Finally, the participants answered a survey evaluating their operating theatre learning environment (Appendix II – Survey 6).

EYESI Simulator Scoring Criteria

EYESi Phaco Simulator evaluate each performance in the following four categories: target achievement, efficiency, instrument handling, and tissue treatment. A positive score is awarded for completing the task. A negative score is given when a mistake occurs. The value of the score is weighted based on the importance of each parameter. The final score of a task is the total awarded score minus the penalty score. The maximum score is 100 and the minimum is 0.

The scoring system for Capsulorhexis and Phaco Divide & Conquer are listed below.

Capsulorrehxis

Target achievement	
Roundness of capsulorrhexis	(0-40)
Centering (distance rhexis center to eye center)	(0-30)
Deviation of rhexis radius from 2.5mm	(0-30)
Maximum radial extension of capsulorhexis	(-100-0)
Local irregularity of capsulorrhexis (spikes)	(-100-0)
Efficiency	
Time	(-20-0)
Operating without red reflex	(-20-0)
Instrument handling	
Open forceps insertion or removal	(-20-0)
Non-horizontal instrument insertion/removal	(-20-0)

Tissue treatment	
Iris contact	(-20-0)
Injured cornea area	(-100-0)

Phaco Divide & Conquer

Target achievement	
Removal lens material	(0-60)
Successful cracking attempts	(0-40)
Efficiency	
Time	(-20-0)
Ultrasonic energy	(-25-0)
Instrument handling	
Non-horizontal instrument insertion/removal	(-20-0)
Tissue treatment	
Capsule damage by ultrasonic energy	(-100-0)
Emulsification near the capsule	(-30-0)
Anterior capsule torn	(-25-0)
Posterior capsule torn	(-50-0)
Damaged zonular fibers	(-100-0)
Iris contact	(-20-0)
Ultrasonic leakage	(-25-0)

Statistical Analysis:

Data collection

EYESi simulator stores data in Excel file format. The data was organized and retrieved via the Administrator Account. It was downloaded on to a USB memory stick and transferred to a computer for analysis.

Statistical program used

SPSS Statistics Version 17.0

Statistical Methods

General linear model for repeated measure ANOVA was used to analyze the variables in each simulator test. The significance level was set at $p_F<0.05$.

Correlation tests were analyzed with Pearson correlation test. The significance level was set at $p<0.05$.

RESULTS

SECTION I

Construct Validity Study

The demographic data of the participants for this study is shown in Table 1. The trainee group had an average of 2 hours of previous EYESi simulator training as required by the Irish College of Ophthalmologists as part of their Basic Surgical Training.

Table 1. Demographic Data of Experts Group And Trainees Group participated in the Construct Validity Study

Group	Experts	Trainees
Total number	N=15	N=18
Male:Female ratio	10:5	7:11
Phacoemulsification exeprience in number of cases performed	Ranged from 500 to >2000	Ranged from 0 to 80
EYESi simulator experience	None except by demonstration	Average 2 hours of previous training

No significant difference between the Expert and Trainee Group was found in the Navigation Level 3, Anti-tremor Level 3 or 4, Forceps Level 4, Cracking & Chopping Level 6 and Bi-manual Level 5 (Table 2). These five modules are skill training modules with a simple goal. Completing these tasks does not require understanding of the complex anatomy and surgical procedures. The purpose of these tasks is to training hand-eye-foot co-ordination. On the other hand, the more complex surgical simulation modules, Capsulorrhexis Level 8 and Phaco Divide & Conquer Level 6, showed significant difference between the Expert and Trainee Group.

Table 2. Repeated Measure ANOVA For Simple Task Modules

Modules	Is there significance difference between Experts and Trainees	Improvement (learning effect) occurred within 5 attempts	Difference in learning effect between groups
Navigation Level 3	No (P_F=0.55)	No (P_F=0.51)	No (P_F=0.70)
Anti-Tremor Level 3 or 4	No (P_F=0.22)	Yes (PF=0.02	No (P_F=0.11)
Forceps Level 4	No (P_F=0.76)	No (P_F=0.18)	No (P_F=0.12)
Cracking & Chopping Level 6	No (P_F=0.50)	No (P_F=0.84)	No (P_F=0.06)
Bi-Manual Level 5	No (P_F=0.12)	No (P_F=0.12)	No (P_F=0.36)

Capsulorrhexis Level 8

The summary of statistical analysis for the experts group versus the trainees group in Capsulorrhexis level 8 is shown in Table 3. The experts performed significantly better than the trainees in the total *Score* (Figure 1) on Capsulorrhexis level 8 (P_F=0.02). The variables under which the experts performed better were *Time* (P_F=0.04. Figure 2) and *Radial Extension* (P_F=0.03, Figure 3). Among the five attempts, *Time* is the only variable that showed improvement as the participants repeated the trial (PF<0.01). There is no difference in the learning effect between the experts and trainees in reducing the time it took to complete the task (P_F=0.5).

Table 3. Repeated Measure ANOVA for Capsulorrhexis Level 8 Variables

Parameters	Experts performed better than the trainees		Improvement (learning curve) occurred within 5 attmepts		Difference in learning effect between two groups	
Score	Yes	p_F=0.02	No	p_F=0.17	No	p_F=0.76
Time	Yes	p_F=0.04	Yes	p_F<0.01	No	p_F=0.5
Roundness	No	p_F=0.08	No	p_F=0.60	No	p_F=0.18
Centreing	No	p_F=0.07	No	p_F=0.58	No	p_F=0.43
Shape	No	p_F=0.13	No	p_F=0.60	No	p_F=0.46
Radial Extension	Yes	p_F=0.03	No	p_F=0.10	No	p_F=0.77
Incision Stress	No	p_F=0.58	No	p_F=0.94	No	p_F=0.62

*See Appendix I - Chart 1 for summary of decriptive data for Capsulorrhexis Level 8.

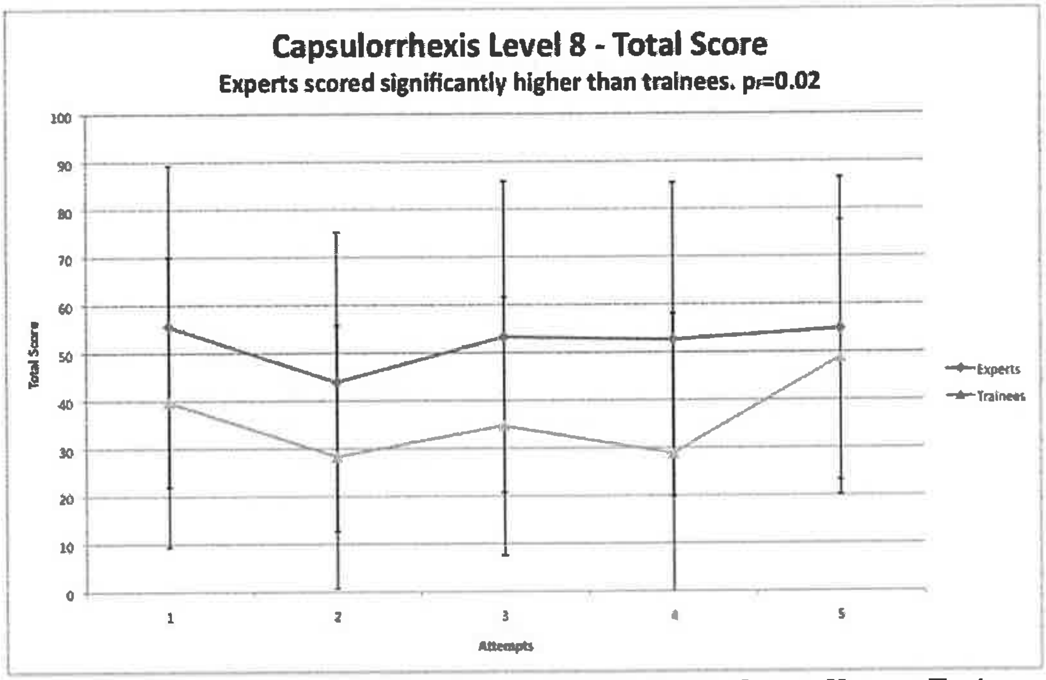


Figure 1 – Capsulorrhexis Level 8 Total Score. Expert Group Versus Trainee Group

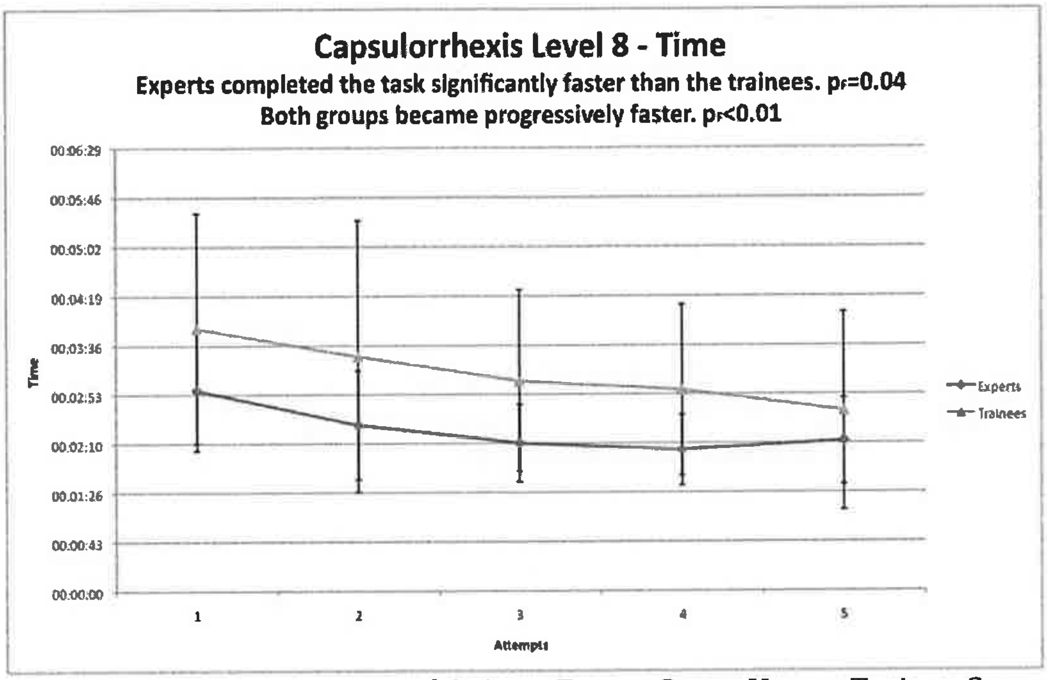


Figure 2 – Capsulorrhexis Level 8 Time. Expert Group Versus Trainee Group

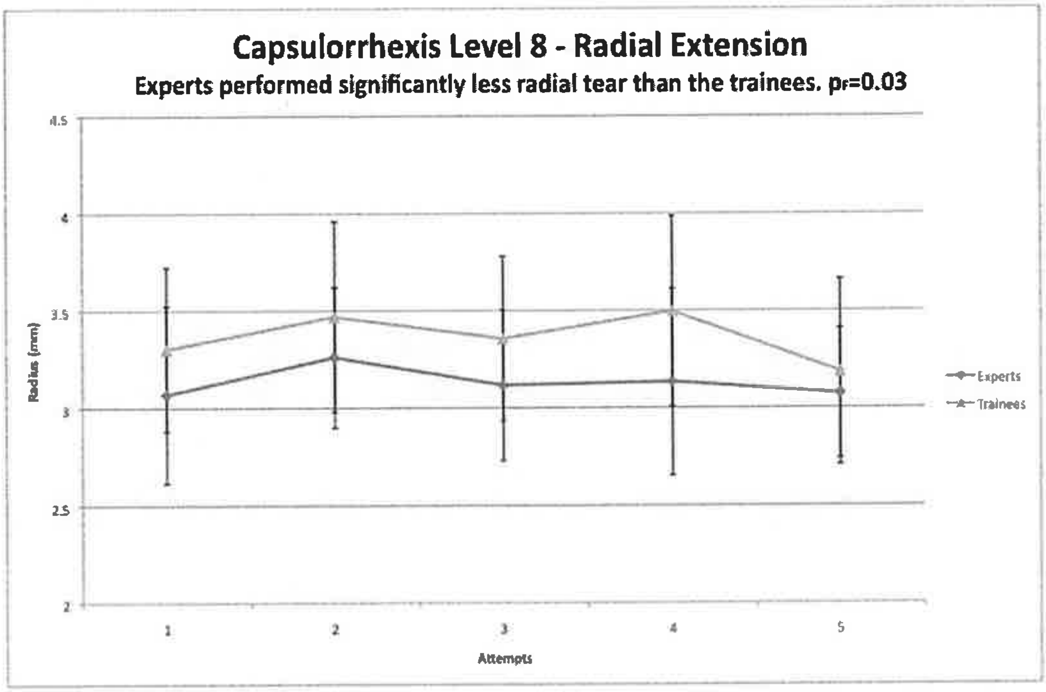


Figure 3 – Capsulorrhexis Level 8 Radial Extension. Expert Group Versus Trainee Group

Phaco Divide and Conquer Level 6

The summary of statistical analysis for the experts group versus the trainees group in Phaco Divide and Conquer Level 6 is shown in Table 4. The experts performed significantly better than the trainees in the total Score (P_F=0.03, Figure 4). The variables that the experts performed better were *Time* (P_F=0.04, Figure 5) *Emulsification Near Capsule* (P_F=0.01, Figure 6) and *Anterior Capsular Torn* (P_F=0.04, Figure 7). Among the five attempts, *Time* (P_F<0.01) and *Odometer* (P_F=0.02, Figure 8) were the only two variables that showed improvement as the participants repeated the trial. Odometer is the measurement of the total path length the tip of the instruments travelled inside the eye.

Table 4. Repeated Measure ANOVA for Phaco Divide and Conquer Level 6 Variables

Parameters	Experts performed better than the trainees		Improvement (learning curve) occurred within 5 attmepts		Difference in learning effect between two groups	
Score	Yes	p_F=0.03	No	p_F=0.95	No	p_F=0.08
Time	Yes	p_F=0.04	Yes	p_F<0.01	No	p_F=0.56
Incision Stress	No	p_F=0.18	No	p_F=0.84	No	p_F=0.95
Iris Contact	No	p_F=0.07	No	p_F=0.65	No	p_F=0.49
Odometer	No	p_F=0.16	Yes	p_F=0.02	No	p_F=0.88
Emulsification Near Capsule	Yes	p_F=0.01	No	p_F=0.12	No	p_F=0.70
Ultrasonic Energy	No	p_F=0.51	No	p_F=0.75	No	p_F=0.51
Damaged Zonule	No	p_F=0.30	No	p_F=0.52	No	p_F=0.20
Posterior Capsule Torn	No	p_F=0.35	No	p_F=0.5	No	p_F=0.45
Anterior Capsule Torn	Yes	p_F=0.04	No	p_F=0.05	No	p_F=0.40

*See Appendix I – Chart 2 for summary of descriptive statistics for Phaco D&C Level 6.

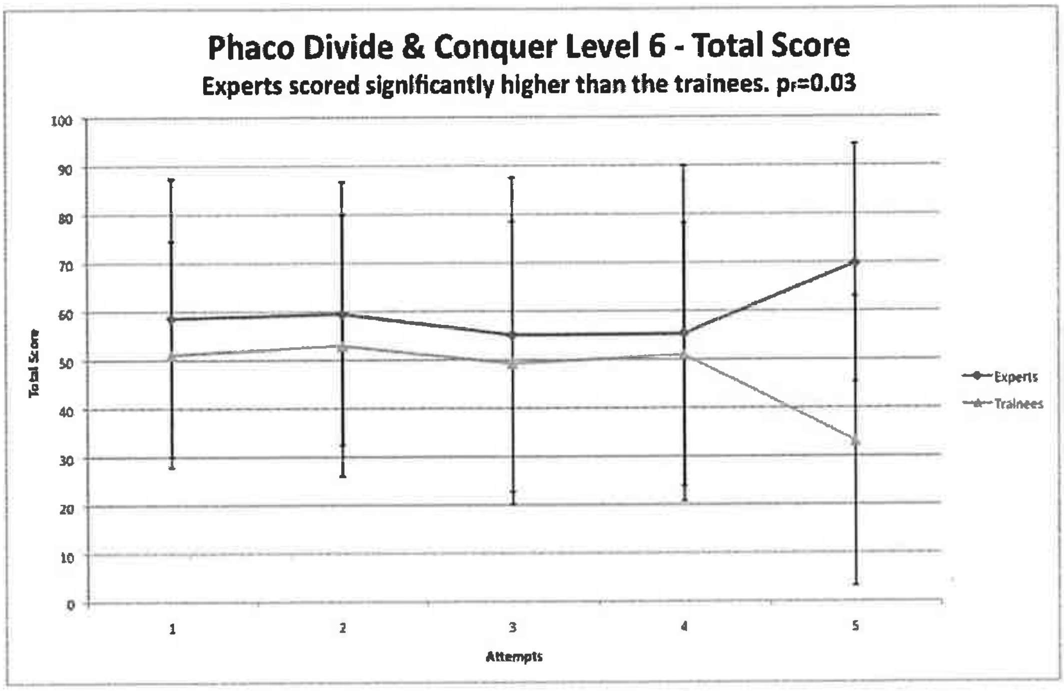


Figure 4 – Phaco Divide and Conquer Level 6 Total Score. Expert Group Versus Trainee Group

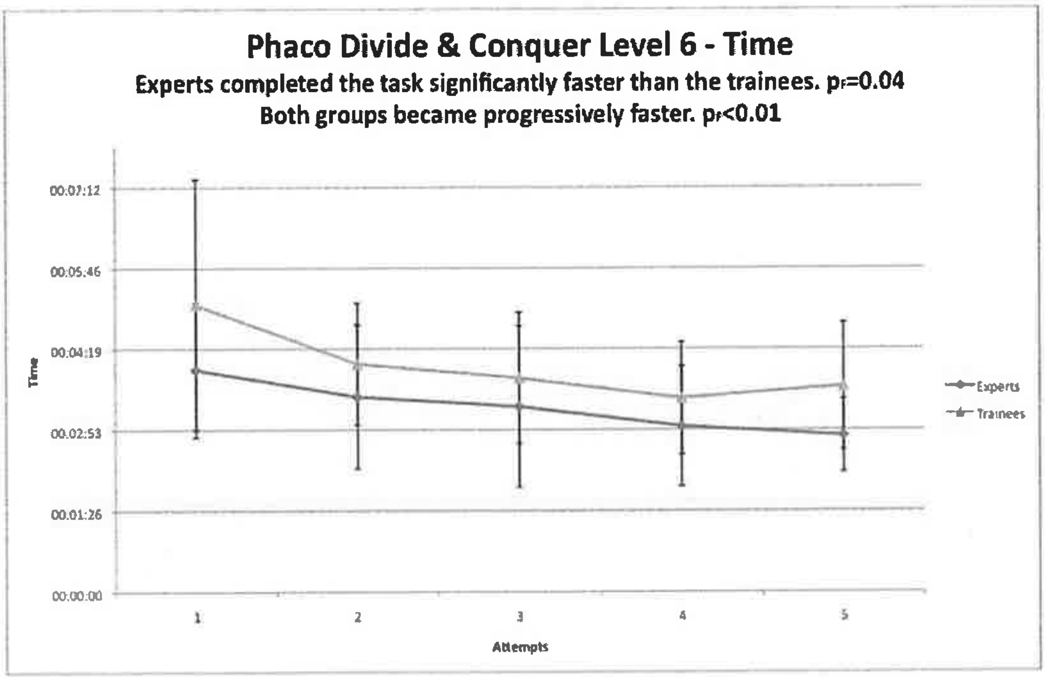


Figure 5 – Phaco Divide and Conquer Level 6 Time. Expert Group Versus Trainee Group

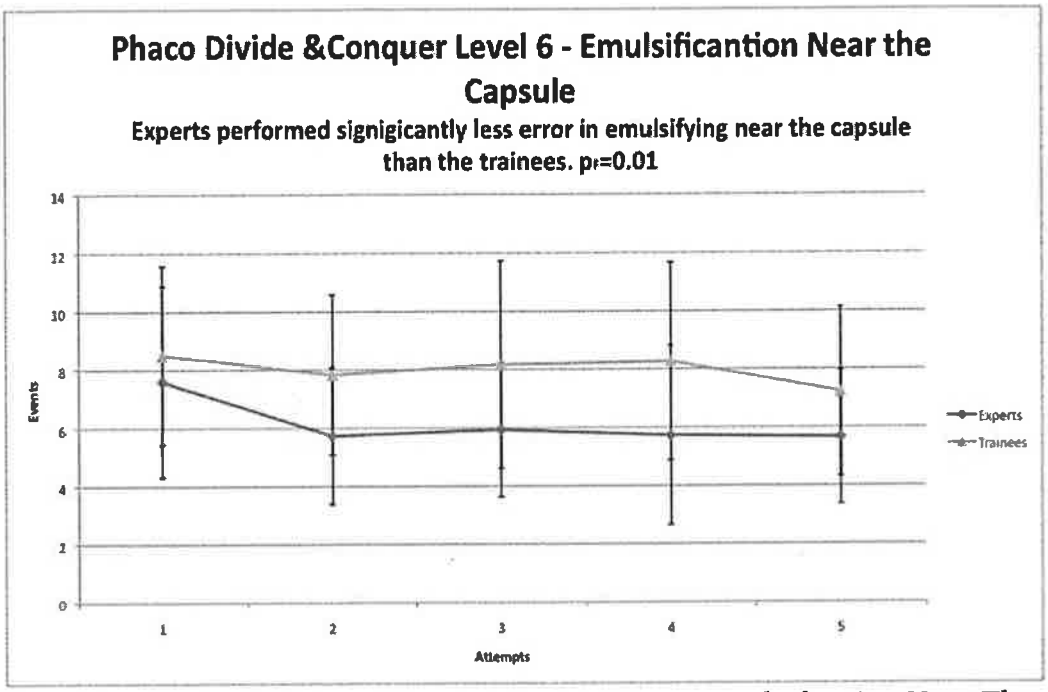


Figure 6 – Phaco Divide and Conquer Level 6 Phacoemulsification Near The Capsule. Expert Group Versus Trainee Group

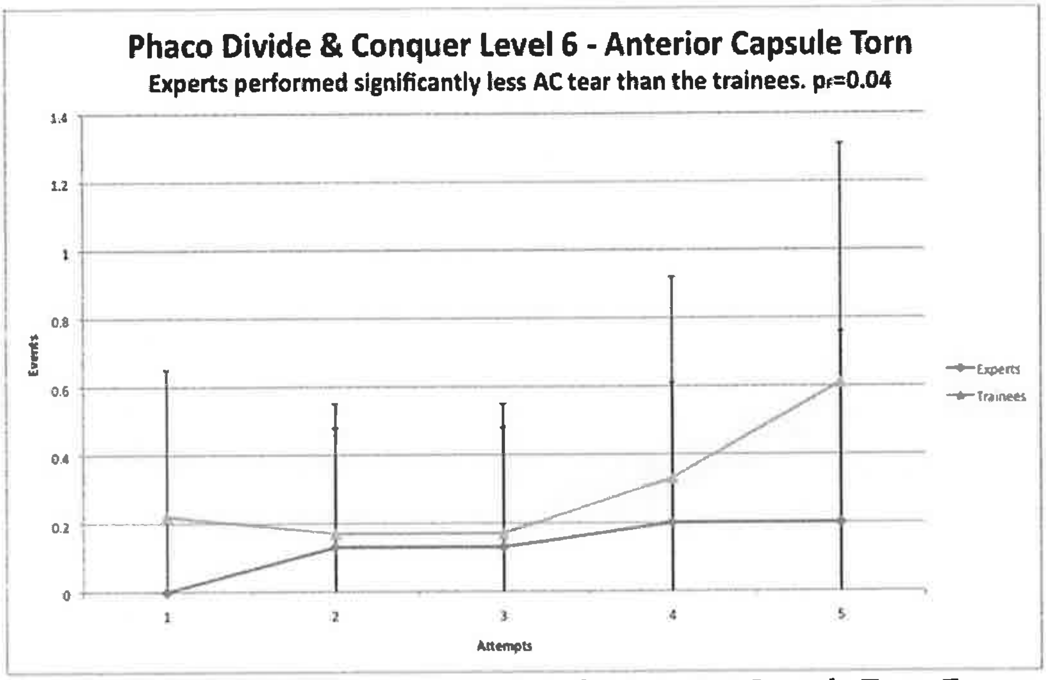


Figure 7 – Phaco Divide and Conquer Level 6 Anterior Capsule Torn. Expert Group Versus Trainee Group

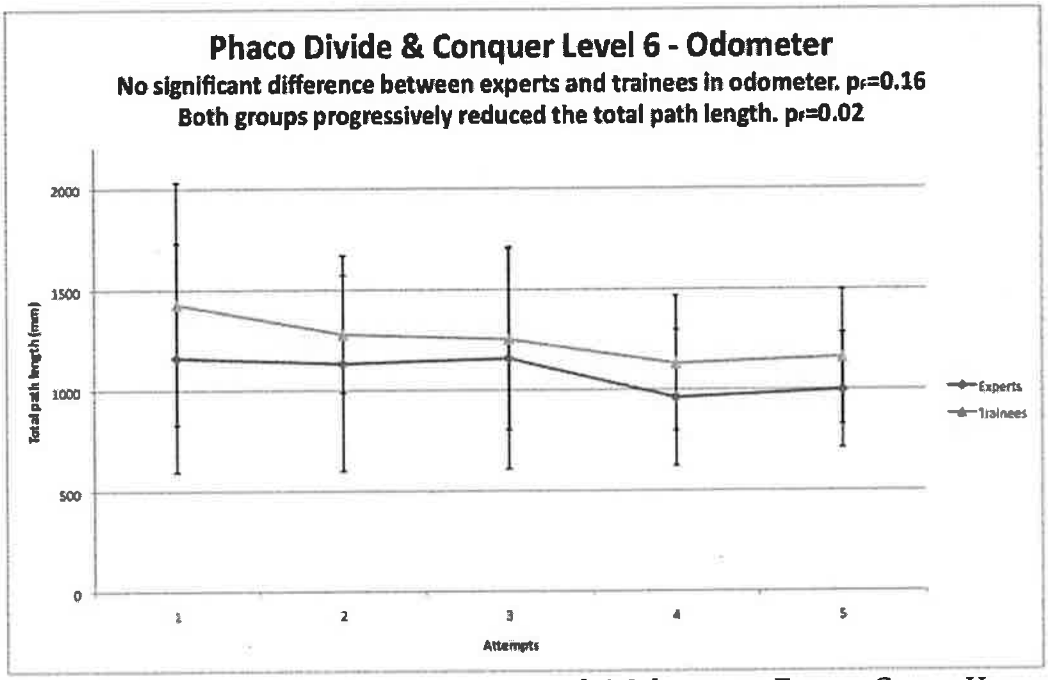


Figure 8 – Phaco Divide and Conquer Level 6 Odometer. Expert Group Versus Trainee Group

Face Validity

The participants' impression on the EYESi simulator as a training tool is summarized in Table 5. All participants agreed that the simulator is a beneficial tool for training junior doctors to acquire appropriate psychomotor skills. All experts and 14 out of 15 trainees thought the level of difficulty set for the assessment was appropriate for trainees. Interestingly, 13 out of 15 in each group did not agree that the trainees should be trained on the simulator until they are proficient before operating on a real patient. However, 27 out of 30 participants thought the simulator will reduce the learning curve of the trainees on real patients and 25 out 30 participants thought the training on the simulator will reduce intraoperative error. Both the experts and the trainees ranked capsulorrhexis as the most important step but also the most common step where mistakes occur.

Table 5. Questionnaire Survey On The Face Validity of EYESi Simulator

Post	Expert (n=15)		Trainees (n=15)	
	Yes	No	Yes	No
EYESi beneficial tool for BST training	15	0	15	0
Level of difficulty appropriate for BST	15	0	14	1
Simulator trains appropriate psychomotor skills	15	0	15	0
BST do reach proficiency before operating on patients	3	12	3	12
Will EYESi reduce learning curve on patients	14	1	13	2
Will EYESi reduce intra-operative error	11	4	14	1
Unreal comprehension of human eye	7	8	9	6
Lack of tactile feedback a problem	8	7	11	4
The most important step cataract surgery	Capsulorrhexis (14/15)		Capsulorrhexis (13/15)	
The most common mistake in cataract surgery	Capsulorrhexis (13/15)		Capsulorrhexis (13/15)	

SECTION II

Setting EYESi Simulator Proficiency Level for Skill Acquisition Curriculum

The proficiency level of the simulator training curriculum is based on the score achieved by the expert group. The mean score of each module achieved by fifteen experts were summarized in Table 6. The mean scores of all five attempts were low with wide standard deviations. These scores were deemed too low for setting the proficiency level. A low standard could result in ineffective training. To obtain a higher mean score and narrower standard deviation, the best 3 out 5 scores were calculated. Still to increase the mean score more, only the top 10 out of the fifteen participants were included. The proficiency score was set provisionally at this level. Note that these scores were from software version 2.4. Prior to the beginning of the training program, an improved version 2.5 was released. The newer version has better simulation graphics and emulated to greater effect on the real surgical environment. Since it was important for the trainees to receive the best training, version 2.5 was used for all the subsequent training and assessment.

The scoring system was also changed in version 2.5 to give more emphasis to important parameters. For example, operating without red reflex is penalized in version 2.5 but not in the older version. Consequently, a more skillful surgeon could score higher than a less skillful one. To ensure that the proficiency score obtained from version 2.4 was still appropriate, a test run to evaluate the achievability of these scores was undertaken. The scores were adjusted to reach the final proficiency score.

Table 6. Performance of Expert Group In EYESi Training Modules

Modules	All 5 attempts (Version 2.4)		Best 3 out of 5 attemtps (Version 2.4)		Top 10 of the best 3 out of 5 attempts (Version 2.4)		Final Proficiency Score (Version 2.5)
	Mean	SD	Mean	SD	Mean	SD	
Navigations (Level 3)	70.7	13.6	75.3	9.2	78.7	3.7	75
Forceps (Level 4)	92.6	8.5	96.4	4.0	98.3	1.3	95
Anti-Tremor (Level 3&4)	65.9	20.2	75.9	14.8	85.4	4.6	80
Bi-Manual (Level 4)	66.8	9.1	70.8	9.1	72.1	8.2	65
Crack & Chopping (Level 6)	72.5	13.1	78.9	11.7	81.3	11.2	90
Capsulorrhexis (Level 8)	52.1	31.7	68.3	22.5	77.1	15.7	80
Phaco Divide and Conquer (Level 6)	59.6	29.3	73.5	15.7	80.1	7.6	85

Designing a Skill Acquisition Curriculum Based on the Proficiency Level

The above proficiency levels were set for the highest level of each module deemed appropriate for the BST training standard. The curriculum was a structured method of delivery to achieve the final level of proficiency. The gate for each module was set at 3 meaning that the trainees were required to achieve equal or higher than the set score on three consecutive occasions in order to pass to the next level.

The curriculum contained two main components: a Capsulorrhexis section and a Phacoemulsification section. Each section began with skill training modules that built up the necessary instrument handling techniques for the surgical simulation modules. The Navigation, Anti-tremor and Forceps modules were for Capsulorrhexis. The Bi-manual, Cracking and Chopping, and Phaco Training were for Phaco Divide and Conquer.

The finalized structured proficiency based progression curriculum is presented in Table 7. This was the required standard that the trainees had to reach in order to exit the training program.

Table 7. Proficiency Base Progression Skill Acquisition Curriculum on EYESi Simulator

Course	Capsulorrhexis				Phacoemulsification			
	Module	Level	Score	Gate	Module	Level	Score	Gate
I	Navigation	1	70	3	Bimanual	1	70	3
		2	75	3		2	70	3
	Forceps	1	90	3	Cracking	1	80	3
		2	90	3		2	80	3
	Anti-tremor	1	80	3	Phaco D &C	1	80	3
		2	80	3		2	80	3
II	Navigation	3	75	3	Bimanual	3	75	3
						4	65	3
	Forceps	3	95	3	Cracking	3	90	3
		4	95	3		4	90	3
	Anti-tremor	3	80	3	Phaco D &C	3	95	3
		4	80	3		4	95	3
	Capsulorrhexis	1	75	3				
		2	75	3				
III	Forceps	4	95	1	Phacodynamic	1	85	3
						2	85	3
	Anti-tremor	3	85	1		3	85	3
		4	85	1				
	Capsulorrhexis	3	75	3				
		4	75	3				
IV	Forceps	4	95	1	Bimanual	5	65	3
	Anti-tremor	3	85	1	Cracking	5	90	3
		4	85	1		6	90	3
	Capsulorrhexis	5	80	3	Phaco D &C	5	85	3
		6	80	3				
V	Forceps	4	95	1	Bimanual	5	65	1
	Anti-tremor	3	85	1	Cracking	7	90	3
		4	85	1		8	90	3
	Capsulorrhexis	7	80	3	Phaco D &C	6	85	3
		8	80	3				

SECTION III

Didactic Lecture For Knowledge Acquisition In Cataract Surgery

Overall, the response from the trainees was positive (Table 8). On a scale of 1 (totally disagree) to 7 (totally agree), they found the lecture had a clear objective (6.6), was interesting (6.5) and useful (6.8). The animation helped to explain abstract concepts (6.9). The lecture helped them to gain understanding of the cataract surgical procedure (6.8) and they would recommend for other trainees to receive this lecture (6.9). The need for more sessions for this lecture differed among the trainees (4.6).

Table 8. Didactic Cataract Surgery Lecture Feedback Questionnaire (Trainees n= 24)

	Mean	SD	Range (1 to 7)
Q1 – Objective	6.6	0.58	5 to 7
Q2 – Interesting	6.5	0.51	6 to 7
Q3 – Useful	6.8	0.38	6 to 7
Q4 – Animation	6.9	0.28	6 to 7
Q5 - Understanding	6.8	0.41	6 to 7
Q6 - Recommendation	6.9	0.20	6 to 7
Q7 – Require more sessions	4.6	2.12	2 to 7

After receiving the lecture on cataract surgery, the trainees perceived they were confident (6.3), and capable (6.4) of learning this material. They gained a sense of achievability (6.3) and could overcome the challenge (5.9) in performing cataract surgery (Table 9).

Table 9. Perceived Confidence for Learning Questionnaire (Trainees n= 24)

	Mean	SD	Range (1 to 7)
Q1 - Confident	6.3	0.61	5 to 7
Q2 - Capable	6.4	0.65	5 to 7
Q3 - Achievable	6.3	0.75	5 to 7
Q4- Challenge	5.9	1.21	3 to 7

SECTION IV

EYESi simulator curriculum for skill acquisition in cataract surgery

In this section, the statistics of simulator training sessions are presented. Ten trainees completed the training curriculum. The total training period, number of sessions, total time spent, total score, and total attempts are summarized in Table 10. The average training period was 64.3 days ranging from26 days to 99 days. The average number of sessions to complete the course was 12.2 ranging from 9 sessions to 15 sessions. The average time to complete the course was 20.2 hours ranging from 14.5 hours to 27.3 hours. The total score was similar among the trainees because this curriculum was proficiency based. When the gate was set at 3, 2 and 1, it took an average of 440.2, 287.8 and 132.2 attempts to reach the proficiency level, respectively. Similarly, the average simulation time to reach gate 3, 2 and 1 were 13.7, 8.8 and 4.0 hours, respectively (Table 11).

Table 10. Summary Statistics Of EYESi Training Sessions And Attempts

User	Training Period (Days)	Number of Sessions	Total Training Time (Minutes)	Total Score (Points)	Attempts Gate = 3	Attempts Gate = 2	Attempts Gate = 1
A	63	11	980	11238	371	224	111
B	99	11	874	11093	346	273	125
C	44	9	867	11188	300	219	105
D	64	14	1637	11025	554	409	168
E	95	14	1246	10953	603	387	189
F	49	14	1340	11118	562	331	153
G	59	10	1141	11103	407	238	142
H	99	15	1587	11154	527	337	135
I	26	9	1030	11098	330	208	100
J	45	15	1428	11252	402	252	94
Mean	64.3	12.2	1213	11122.2	440.2	287.8	132.2
SD	25.5	2.44	281.00	91.59	110.47	73.00	31.23

*The Users were randomly coded with alphabets to provide confidentiality of the trainees

Table 11. Summary Statistics of EYESi Training Time

User	Total Time Gate = 3	Total Time Gate = 2	Total Time Gate = 1	Instrument Time Gate = 3	Instrument Time Gate = 2	Instrument Time Gate = 1
A	10:46:13	05:59:39	03:03:27	08:44:00	04:48:03	02:21:08
B	09:28:04	07:21:19	03:03:25	07:51:42	06:04:25	02:28:19
C	09:48:48	07:30:16	03:15:40	08:13:49	06:18:42	02:37:56
D	19:30:50	13:06:38	05:21:52	17:12:10	11:24:05	04:36:25
E	15:16:21	10:06:15	04:06:50	12:27:22	08:11:45	03:13:26
F	14:59:12	08:34:14	04:13:24	12:21:50	07:01:24	03:24:22
G	12:48:07	07:30:56	04:47:58	09:53:23	05:49:10	03:41:03
H	17:17:56	11:56:45	05:23:12	14:36:35	10:03:32	04:23:48
I	10:49:49	07:08:51	03:28:46	08:52:20	05:50:18	02:39:17
J	16:37:50	08:40:57	03:41:05	14:35:49	07:31:32	03:12:00
Average	13:44:19	08:47:35	04:02:34	11:28:54	07:18:18	03:15:46

The attempts and time taken to reach three consecutive proficiency scores in each module are summarized in Table 12. The module that took the longest time to complete was Phaco D&C Level 5 (10.23%) followed by Capsulorrhexis Level 8 (8.82%). The module that took the most number of attempts to complete was Capsulorrhexis Level 8 (274 trials) followed by Phaco D&C Level 3 (243 trials).

Table 12. Summary of Attempts and Time by Modules From 10 Trainees

Task		Attempts Gate = 3	Time Gate = 3	Time Instrument In The Eye	Percentage Of Total Time
Capsulorrhexis	Level 1	229	10:44:09	09:30:56	8.12%
	Level 2	66	02:35:43	02:15:00	1.92%
	Level 3	119	07:16:28	05:55:47	5.06%
	Level 4	149	08:36:14	07:11:41	6.14%
	Level 5	101	06:15:48	05:21:41	4.58%
	Level 6	165	08:07:28	06:43:46	5.74%
	Level 7	86	05:11:20	04:27:28	3.80%
	Level 8	274	12:37:34	10:19:29	8.82%
Cataract Anti-Tremor Training	Level 1	63	00:42:48	00:29:51	0.42%
	Level 2	136	01:23:16	01:01:12	0.87%
	Level 3	183	02:26:59	01:54:36	1.63%
	Level 4	76	00:55:44	00:42:36	0.60%

Cataract Bimanual Training	Level 1	58	00:55:06	00:41:00	0.58%
	Level 2	90	01:46:23	01:25:49	1.22%
	Level 3	192	02:57:04	02:17:07	1.95%
	Level 4	150	03:04:00	02:32:06	2.16%
	Level 5	74	01:20:25	01:06:58	0.95%
Cataract Cracking & Chopping Training	Level 1	31	00:19:50	00:14:04	0.20%
	Level 2	30	00:16:13	00:14:34	0.20%
	Level 3	43	00:29:23	00:20:04	0.28%
	Level 4	97	01:18:28	01:02:21	0.88%
	Level 5	33	00:20:16	00:14:58	0.21%
	Level 6	31	00:15:46	00:11:53	0.16%
	Level 7	44	00:34:21	00:27:12	0.38%
	Level 8	66	01:05:27	00:54:24	0.77%
Cataract Forceps Training	Level 1	122	02:42:12	02:17:09	1.95%
	Level 2	121	02:24:56	01:58:25	1.68%
	Level 3	138	02:39:06	02:13:45	1.90%
	Level 4	67	01:03:44	00:51:53	0.73%
Cataract Navigation Training	Level 1	88	02:33:19	02:09:24	1.84%
	Level 2	75	01:27:59	01:14:34	1.06%
	Level 3	179	05:21:43	04:38:15	3.96%
Phaco Divide and Conquer	Level 1	49	01:28:54	00:51:32	0.73%
	Level 2	38	01:43:52	01:26:39	1.23%
	Level 3	243	06:23:28	05:17:15	4.51%
	Level 4	147	02:42:13	02:16:59	1.95%
	Level 5	153	13:13:49	11:58:43	10.23%
	Level 6	90	07:44:49	07:13:50	6.17%
Phaco Training	Level 1	91	01:33:08	00:52:27	0.74%
	Level 2	125	01:22:00	00:58:05	0.82%
	Level 3	96	01:11:06	00:47:16	0.67%
CAPSU-III Anti-Tremor	Level 3	29	00:24:48	00:19:34	0.27%
	Level 4	19	00:15:05	00:12:02	0.17%
CAPSU-III Forceps	Level 4	15	00:17:47	00:14:45	0.21%
CAPSU-IV Anti-Tremor	Level 3	38	00:27:45	00:21:37	0.30%
	Level 4	16	00:12:07	00:09:39	0.13%
CAPSU-IV Forceps	Level 4	15	00:16:09	00:13:13	0.18%
CAPSU-V Anti-Tremor	Level 3	16	00:10:45	00:08:36	0.12%
	Level 4	12	00:08:32	00:06:33	0.09%
CAPSU-V Forceps	Level 4	20	00:17:33	00:14:26	0.20%
PHACO-V Bi-Manual	Level 5	18	00:24:24	00:20:16	0.28%
Total		4606	140:07:26	117:03:25	100%

The effect of setting the gate of reaching proficiency level consecutively thrice, twice or once for each module is summarized in Table 13. This data indicates the level of difficulty for each task. In an easy module such as Cracking and Chopping training, an average of 4.3 attempts would achieve the proficiency level 3 times. Whereas in Capsulorrhexis, it took an average of 13.9 attempts to reach the proficiency level 3 times, indicating that this was a difficult module.

Table 13. Summary of Average Attempts To Reach The Proficiency Level Consecutively Thrice, Twice and Once For Each Module

Task		Attempt Gate = 3		Attempt Gate = 2		Attempt Gate = 1	
		Mean	SD	Mean	SD	Mean	SD
Capsulorrhexis	Level 1	22.9	16.34	9.1	6.65	2.9	1.85
	Level 2	6.6	2.98	5.6	2.98	2.2	1.61
	Level 3	11.9	6.04	6.6	3.40	3.1	2.64
	Level 4	14.9	11.43	7.4	7.70	1.2	0.63
	Level 5	10.1	4.97	6.8	5.24	1.9	1.19
	Level 6	16.5	13.04	7.1	6.82	2	1.05
	Level 7	8.6	4.83	4.7	2.66	2.3	1.41
	Level 8	27.2	20.44	10.5	11.78	2.7	3.33
Cataract Anti-Tremor Training	Level 1	6.3	3.91	4.5	2.83	2.4	1.17
	Level 2	13.6	10.85	10.3	9.55	6.5	8.11
	Level 3	18.2	19.34	10.4	9.16	6.4	7.61
	Level 4	7.5	5.12	3.8	1.39	1.7	0.94
Cataract Bimanual Training	Level 1	5.8	5.65	3.1	2.51	1.3	0.67
	Level 2	9	9.04	7.7	9.20	3.7	4.64
	Level 3	19.2	22.17	14.8	17.93	6.8	7.98
	Level 4	15	11.94	9.7	11.03	4.1	3.69
	Level 5	7.3	8.17	5.1	5.36	2.2	1.68
Cataract Cracking & Chopping Training	Level 1	3.1	0.31	2.1	0.31	1.1	0.31
	Level 2	3	0	2	0	1	0
	Level 3	4.3	1.25	3.3	1.25	1.8	0.91
	Level 4	9.7	8.6	4.9	3.72	1.6	0.9
	Level 5	3.3	0.67	2.3	0.67	1.1	0.31
	Level 6	3.1	0.31	2.1	0.31	1.1	0.31
	Level 7	4.4	2.36	2.4	0.69	1.2	0.42
	Level 8	6.6	4.67	4.1	3.95	1.5	0.84
Cataract Forceps Training	Level 1	12.2	11.85	9.3	9.44	4.6	3.43
	Level 2	12.1	12.32	8.7	8.62	6.3	9.20

	Level 3	13.8	12.66	12.4	11.77	5.4	4.64
	Level 4	6.7	6.03	3.3	1.49	1.4	0.51
Cataract Navigation Training	Level 1	8.8	4.41	6.2	4.07	4.5	2.95
	Level 2	7.5	6.29	5.9	5.87	1.5	0.70
	Level 3	17.8	13.29	11.7	10.07	5.3	5.37
Phaco Divide and Conquer	Level 1	4.9	2.51	2.7	1.33	1.5	1.26
	Level 2	3.8	1.47	2.5	1.26	1.3	0.67
	Level 3	24.3	21.74	21.5	21.91	8.6	6.55
	Level 4	14.7	6.49	10.8	5.15	5.1	2.96
	Level 5	15.3	14.99	10.5	5.68	5.1	4.55
	Level 6	9	5.24	6.7	5.85	2.9	2.88
Phaco Training	Level 1	9.1	5.15	7.5	5.31	4.4	1.64
	Level 2	12.5	9.83	9.1	8.96	6.8	8.81
	Level 3	9.6	4.37	8.6	4.37	3.7	2.05

The training history of each trainee was analyzed against his or her aptitude test scores for correlation (Table 14). The Cube Comparison test was found to have significant negative correlation with the number of sessions (r=-0.639 p=0.047, Figure 9), total time (r=-0.710, p=0.021, Figure 10), and attempts (r=-0.736, p=0.015, Figure 11) spent to complete the curriculum. The Map Planning test had negative correlation with the number of attempts (r=-0.722, p=0.018, Figure 12). Negative correlation indicates that the higher the score they achieved in the aptitude test, the quicker they reached proficiency level.

Table 14. Correlation Test (See Appendix I - Chart 3 for Aptitude Scores)

		Number of Sessions	Attempts	Total Time
Card Rotation	Pearson Correlation	-.394	-.125	-.547
	Sig. (2-tailed)	.260	.730	.102
Cube Comparison	Pearson Correlation	-.639*	-.736*	-.710*
	Sig. (2-tailed)	.047	.015	.021
Map Planning	Pearson Correlation	-.510	-.722*	-.625
	Sig. (2-tailed)	.132	.018	.054

*. Correlation is significant at the 0.05 level (2 tailed)

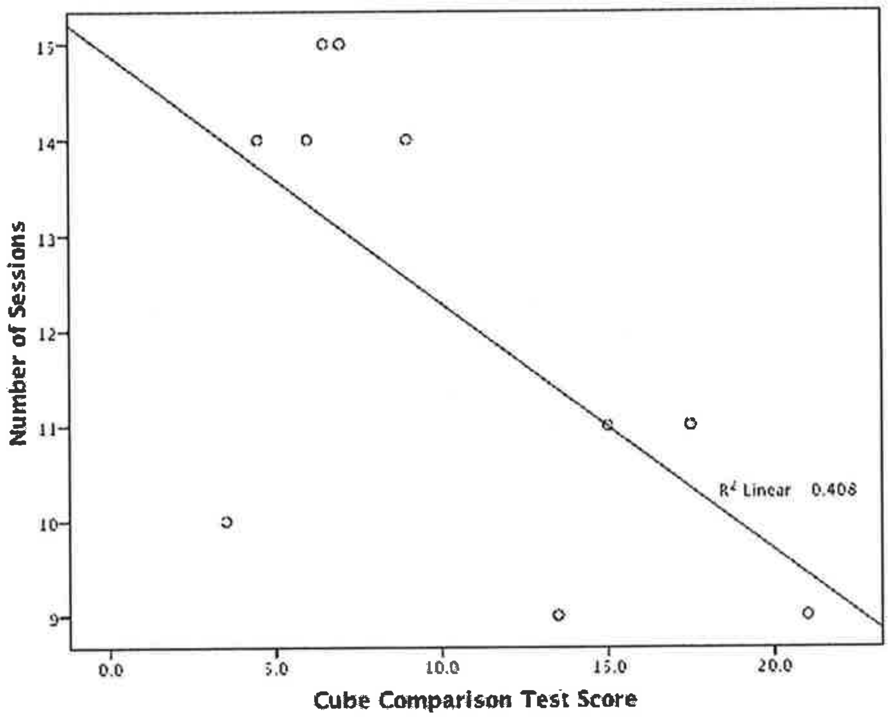


Figure 9. Correlation between cube comparison test score and number of sessions required to finish the proficiency based EYESi curriculum (r=-0.639, p=0.047)

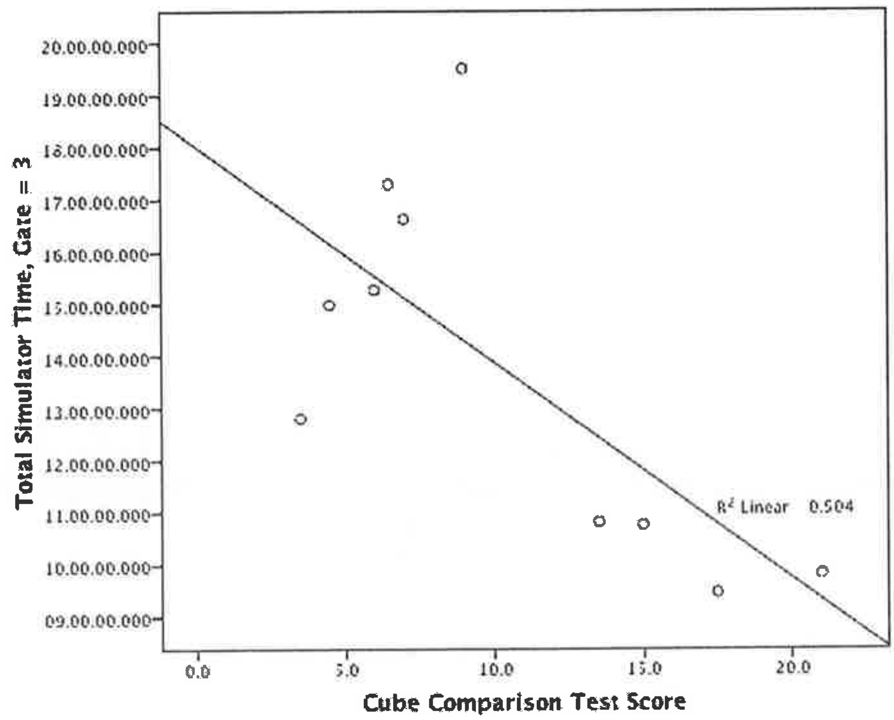


Figure 10. Correlation between cube comparison test score and total simulator time required to finish the proficiency based EYESi curriculum (r=-0.71, p=0.021)

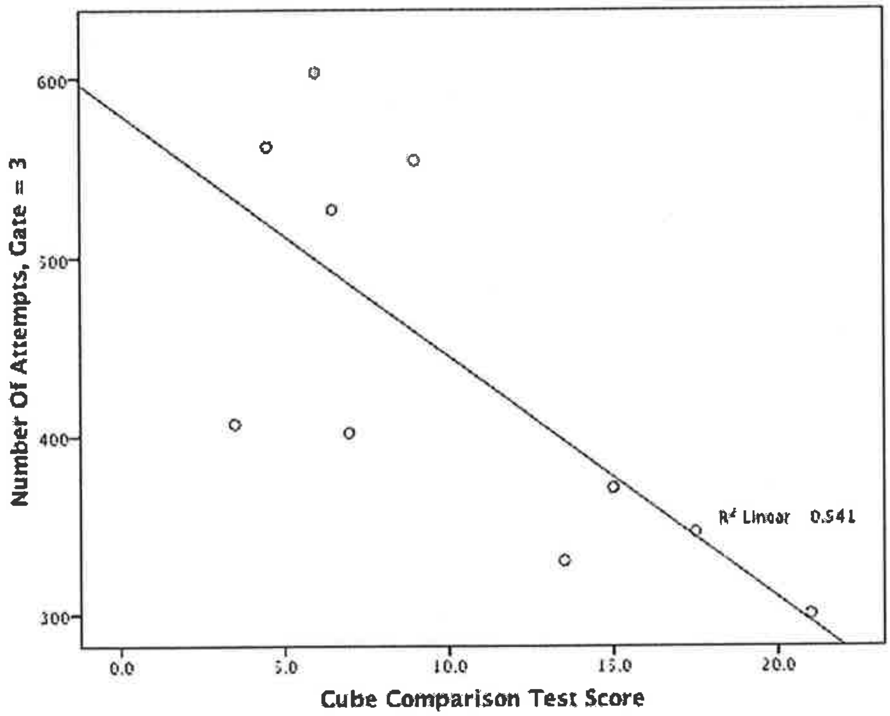


Figure 11. Correlation between cube comparison test score and number of attempts required to finish the proficiency based EYESi curriculum (r=-0.736, p=0.015)

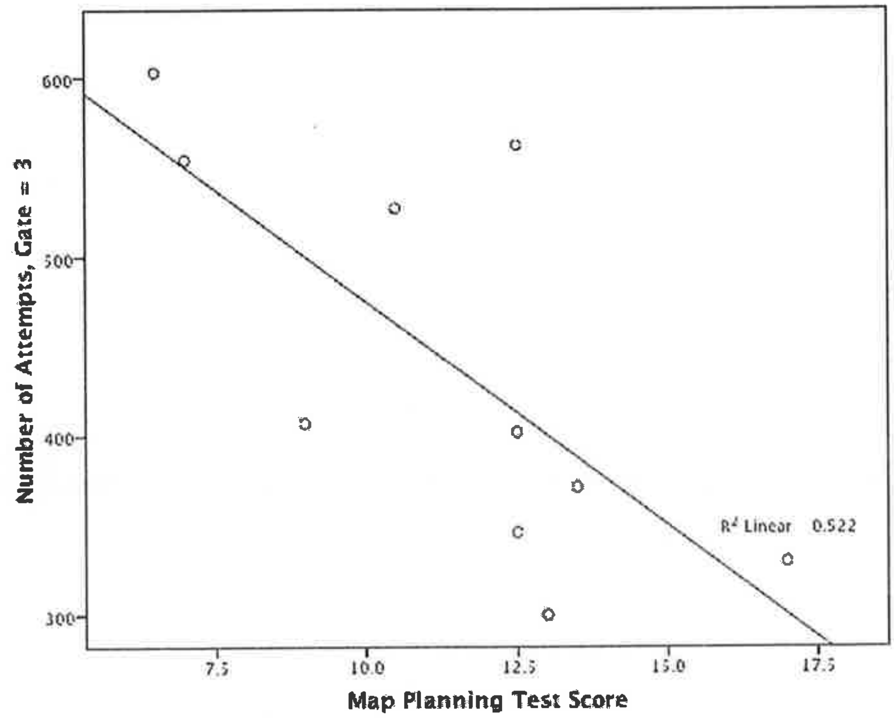


Figure 12. Correlation between map planning test score and number of attempts required to finish the proficiency based EYESi curriculum (r=-0.722, p=0.018)

Trainees' Feedback On The EYESi Simulator Learning Experiences

After completing the training curriculum, trainees were asked to give feedback on the simulator as a training tool based on their experience. Overall the responses were positive (Table 15). This group of trainees thought that the skill training curriculum increased their understanding of cataract surgery and improved their techniques as well as their confidence in being a better surgeon. They also thought that the skills learned from the simulator training could be transferred to their operative skills in the theatre. More importantly, all except one did not think they learned bad techniques from the simulator training. However, when ask about specific areas of improvement, there was a wide range of opinion. Nevertheless, all trainees agreed that the simulator should be part of their basic surgical training and the proficiency level in this curriculum is not inappropriate.

Table 15. Survey – Training On The EYESi Simulator Questionnaire

Trainees (n=10)	A	B	C	D	E	F	G	H	I	J	Mean	SD
Understanding	6	6	7	7	6	5	6	6	7	7	6.3	0.67
Techniques	6	5	7	7	6	6	7	6	6	7	6.3	0.67
Confidence	6	5	6	7	6	4	7	6	5	7	5.9	0.99
Become better	6	6	7	7	6	5	4	6	5	6	5.8	0.92
Skill transfer	6	6	7	7	6	6	7	6	6	7	6.4	0.51
BAD techniques	2	2	1	6	2	3	4	1	3	2	2.6	1.51
Hand eye coordination	4	7	7	7	2	3	7	7	6	6	5.6	1.89
Improvement in capsulorrhexis	1	5	7	6	6	6	7	6	4	7	5.5	1.84
Improvement in phaco divide & conquer	2	5	6	7	4	5	7	6	5	6	5.3	1.49
Mandatory EYESi training	7	7	7	7	5	6	6	7	6	7	6.5	0.71
Proficiency level difficulty	5	4	4	4	4	5	4	4	5	4	4.3	0.48

The trainees were also asked to give feedback on their EYESi simulator trainer for this study (Table 16). They felt the trainer had made the learning environment effective for them to complete the course.

Table 16. Survey – Learning Climate Questionnaire

Trainees (n=10)	A	B	C	D	E	F	G	H	I	J	Mean	SD
Choice and reasons	7	6	7	7	7	7	7	6	6	7	6.7	0.48
Felt understood	6	6	7	7	7	7	7	7	6	7	6.7	0.48
Convey confidence	6	7	7	7	7	7	7	6	7	6	6.7	0.48
Encourage to ask	6	7	6	7	7	7	7	7	6	7	6.7	0.48
Listen	5	7	7	7	7	7	6	6	6	6	6.4	0.70
Allows self development	6	6	7	7	7	7	7	7	7	7	6.8	0.42

A survey of how the trainees in the BST program rate their training environment in a hospital is summarized in Table 17. Most trainees felt that they were part of a group in the surgical team (4.2 out of 5), being supported in achieving their potential (4.1 out of 5) and were becoming more self confident in performing cataract surgery (4.1 out of 5). Nevertheless, most trainees felt that they were not confident enough to express themselves (3.8 out of 5) and did not have enough opportunity to master skills (3.6 out of 5).

Table 17. Survey – Maslow's Learning Environment For Cataract Surgery Trainings In Ireland. Trainees (n=17) Mean Duration in Ophthalmology Training Post 10.9 Months (SD 5.2, Range 5 -21 Months)

Features	Mean	SD	Range
Comfortable environment	3.9	0.83	3 to 5
Confident that can express yourself	3.8	0.83	2 to 5
Feel part of a group	4.2	0.53	3 to 5
Becoming self confident	4.1	0.69	3 to 5
Have the opportunity to master skills	3.6	0.99	2 to 5
Supported in achieving potentials	4.1	1.03	1 to 5

SECTION V

Assessment Comparing Training vs. Non-Training Groups

Participants in both the training (n=10) and non-training (n=10) groups were assessed on the simulator with standardized protocol. The trained group performed significantly better ($P_F<0.05$) than the non-trained group in all modules tested. The modules tested were Navigation Level 3 (Table 18), Anti-Tremor Level 3 (Table 19), Anti-Tremor Level 4 (Table 20), Forceps Training (Table 21), Capsulorrhexis Level 8 (Table 22), Bi-Manual Training (Table 23), Cracking and Chopping Level 4 (Table 24), and Phaco Divide & Conquer Level 6 (Table 25). The parameters that training improves are shown in following tables for each module.

Table 18. Repeated Measure ANOVA for Navigation Level 3 Variables In The Training Versus Non-Training Groups

Parameters	Does Training Improves:		Learning Effects	
Overall score	Yes	$P_F<0.01$	No	$P_F=0.26$
Injured cornea area score	Yes	$P_F=0.04$	No	$P_F=0.34$
Injured cornea area value	Yes	$P_F=0.04$	No	$P_F=0.34$
Instrument slipped out of sphere no. Events	Yes	$P_F<0.01$	No	$P_F=0.54$
Odometer score	Yes	$P_F<0.01$	No	$P_F=0.16$
Odometer value	Yes	$P_F<0.01$	No	$P_F=0.11$
Operating without red reflex duration	No	$P_F=0.06$	No	$P_F=0.87$
Operating without red reflex score	No	$P_F=0.07$	No	$P_F=0.87$
Time duration	Yes	$P_F<0.01$	No	$P_F=0.20$
Time score	Yes	$P_F<0.01$	No	$P_F=0.21$
Time (with instruments inserted) duration	Yes	$P_F<0.01$	No	$P_F=0.12$

*See Appendix I - Chart 4 for summary of descriptive statistics.

Table 19. Repeated Measure ANOVA For Anti-Tremor Level 3 Variables In The Training Versus Non-Training Groups

Parameters	Does Training Improves:		Learning Effect	
Overall Score	Yes	P_F=0.01	No	P_F=0.65
Average Tremor	No	P_F=0.06	No	P_F=0.32
Operating Without Red Reflex (Duration)	No	P_F=0.06	No	P_F=0.62
Operating Without Red Reflex (Score)	No	P_F=0.06	No	P_F=0.58
Out Of Tolerance Percentage (Value)	Yes	P_F=0.02	No	P_F=0.68
Out of Tolerance Percentage (Score)	Yes	P_F=0.02	No	P_F=0.75
Time (Duration)	Yes	P_F=0.01	Yes	P_F<0.01
Time Duration (Score)	No	P_F=0.05	Yes	P_F=0.01
Time (With Instrument Inserted Duration)	Yes	P_F=0.02	Yes	P_F=0.03

*See Appendix I - Chart 5 for summary of descriptive statistics

Table 20. Repeated Measure ANOVA for Anti-Tremor Level 4 Variables In The Training Versus Non-Training Groups

Parameters	Does Training Improves:		Learning Effect	
Overall Score	Yes	P_F=0.01	No	P_F=0.05
Average Tremor	Yes	P_F=0.01	Yes	P_F=0.02
Operating Without Red Reflex (Duration)	Yes	P_F=0.02	Yes	P_F=0.04
Operating Without Red Reflex (Score)	Yes	P_F=0.03	Yes	P_F=0.04
Out Of Tolerance Percentage (Value)	Yes	P_F<0.01	No	P_F=0.08
Out of Tolerance Percentage (Score)	Yes	P_F<0.01	No	P_F=0.08
Time (Duration)	No	P_F=0.07	No	P_F=0.30
Time Duration (Score)	No	P_F=0.11	No	P_F=0.97
Time (With Instrument Inserted Duration)	No	P_F=0.12	No	P_F=0.28

*See Appendix I – Chart 6 for summary of descriptive statistics.

Table 21. Repeated Measure ANOVA for Forceps Level 4 Variables In The Training Versus Non-Training Groups

Parameters	Does Training Improves:		Learning Effect	
Overall score	Yes	$P_F<0.01$	No	$P_F=0.18$
Injured cornea area score	No	$P_F=0.19$	No	$P_F=0.55$
Injured cornea area value	No	$P_F=0.19$	No	$P_F=0.55$
Injured lens area score	Yes	$P_F=0.01$	No	$P_F=0.92$
Injured lens area value	Yes	$P_F=0.01$	No	$P_F=0.92$
Odometer score	Yes	$P_F<0.01$	No	$P_F=0.24$
Odometer value	Yes	$P_F<0.01$	No	$P_F=0.10$
Operating without red reflex duration	Yes	$P_F=0.04$	No	$P_F=0.18$
Operating without red reflex score	No	$P_F=0.05$	Yes	$P_F=0.18$
Time duration	Yes	$P_F<0.01$	Yes	$P_F=0.01$
Time score	Yes	$P_F<0.01$	Yes	$P_F=0.02$
Time (with instruments inserted) duration	Yes	$P_F<0.01$	Yes	$P_F<0.01$

*See Appendix I – Chart 7 for summary of descriptive statistics.

Table 22. Repeated Measure AVOVA for Capsulorrhexis Level 8 Variables In The Training Versus Non-Training Groups

Parameters	Does Training Improves:		Learning Effect	
Overall score	Yes	$P_F<0.01$	No	$P_F=0.24$
Average radius of Capsulorrhexis value	Yes	$P_F=0.04$	No	$P_F=0.33$
Centering (distance rhexis center to eye center) score	No	$P_F=0.08$	No	$P_F=0.15$
Centering (distance rhexis center to eye center) value	No	$P_F=0.10$	No	$P_F=0.15$
Deviation of rhexis radius from 2.5mm score	Yes	$P_F=0.02$	No	$P_F=0.89$
Deviation of rhexis radius from 2.5mm value	No	$P_F=0.07$	No	$P_F=0.97$
Injured cornea area score	Yes	$P_F=0.01$	No	$P_F=0.73$
Injured cornea area value	Yes	$P_F=0.01$	No	$P_F=0.72$
Local irregularity of Capsulorrhexis (spikes) score	Yes	$P_F=0.03$	No	$P_F=0.49$
Local irregularity of Capsulorrhexis (spikes) value	Yes	$P_F=0.03$	No	$P_F=0.49$
Maximum radial extension of	Yes	$P_F<0.01$	No	$P_F=0.07$

Capsulorrhexis score				
Maximum radial extension of Capsulorrhexis value	Yes	$P_F<0.01$	Yes	$P_F=0.03$
Non-horizontal instrument insertion/removal no. Events	Yes	$P_F=0.049$	No	$P_F=0.23$
Non-horizontal instrument insertion/removal score	Yes	$P_F=0.049$	No	$P_F=0.23$
Operating without red reflex duration	Yes	$P_F=0.04$	No	$P_F=0.96$
Operating without red reflex score	Yes	$P_F=0.02$	No	$P_F=0.71$
Roundness of Capsulorrhexis score	Yes	$P_F<0.01$	No	$P_F=0.79$
Roundness of Capsulorrhexis value	Yes	$P_F<0.01$	No	$P_F=0.79$
Time duration	No	$P_F=0.82$	No	$P_F=0.36$
Time score	No	$P_F=0.77$	No	$P_F=0.39$
Time (with instruments inserted) duration	No	$P_F=0.59$	No	$P_F=0.62$

*See Appendix I – Chart 8 for summary of descriptive statistics.

Table 23. Repeated Measure ANOVA for Bi-Manual Level 4 Variables In The Training Versus Non-Training Groups

Parameters	Does Training Improves:		Learning Effect	
Over All Score	Yes	$P_F<0.01$	No	$P_F=0.07$
Instrument slipped out of sphere no. (Events)	Yes	$P_F<0.01$	No	$P_F=0.61$
Instrument slipped out of sphere (Score)	Yes	$P_F=0.02$	No	$P_F=0.07$
Odometer (Score)	Yes	$P_F=0.01$	No	$P_F=0.17$
Odometer (Value)	Yes	$P_F=0.02$	No	$P_F=0.27$
Operating without red reflex (Duration)	Yes	$P_F=0.02$	No	$P_F=0.92$
Operating without red reflex (Score)	Yes	$P_F=0.01$	No	$P_F=0.78$
Time (Duration)	Yes	$P_F=0.02$	Yes	$P_F=0.04$
Time (Score)	Yes	$P_F=0.02$	Yes	$P_F=0.04$
Time with instruments inserted (Duration)	Yes	$P_F<0.01$	Yes	$P_F=0.03$

*See Appendix 9 for summary of descriptive statistics.

Table 24. Repeated Measure ANOVA for Cracking & Chopping Level 4 Variables In The Training Versus Non-Training Groups

Parameters	Does Training Improves:		Learning Effect	
Overall Score	Yes	$P_F<0.01$	No	$P_F=0.26$
Instrument slipped out of sphere no. (Events)	Yes	$P_F<0.01$	No	$P_F=0.10$
Instrument slipped out of sphere no. (Score)	Yes	$P_F<0.01$	No	$P_F=0.34$
Operating without red reflex (Duration)	Yes	$P_F=0.01$	No	$P_F=0.79$
Operating without red reflex (Score)	Yes	$P_F=0.01$	No	$P_F=0.79$
Time (Duration)	Yes	$P_F<0.01$	No	$P_F=0.18$
Time (Score)	Yes	$P_F<0.01$	No	$P_F=0.26$
Time (with instruments inserted)	Yes	$P_F<0.01$	No	$P_F=0.16$

*See Appendix I – Chart 10 for summary of descriptive statistics

Table 25. Repeated Measure ANOVA for Phaco Divide & Conquer Level 6 Variable In The Training Versus Non-Training Groups

Parameters	Does Training Improves:		Learning Effect:	
Overall score	Yes	$P_F=0.01$	No	$P_F=0.47$
Anterior capsule torn no. Events	No	$P_F=0.45$	No	$P_F=1.00$
Anterior capsule torn score	No	$P_F=0.45$	No	$P_F=1.00$
Capsule damage by ultrasonic energy no. Events	Yes	$P_F=0.01$	No	$P_F=0.22$
Capsule damage by ultrasonic energy score	Yes	$P_F=0.01$	No	$P_F=0.22$
Emulsification near the capsule no. Events	Yes	$P_F=0.04$	No	$P_F=0.59$
Emulsification near the capsule score	Yes	$P_F=0.02$	No	$P_F=0.92$
Non-horizontal instrument insertion/removal no. Events	Yes	$P_F=0.01$	No	$P_F=0.95$
Non-horizontal instrument insertion/removal score	Yes	$P_F=0.01$	No	$P_F=0.95$
Odometer value	No	$P_F=0.05$	Yes	$P_F<0.01$
Posterior capsule torn no. Events	No	$P_F=0.06$	No	$P_F=0.13$
Posterior capsule torn score	No	$P_F=0.05$	No	$P_F=0.25$
Successful cracking attempts score	Yes	$P_F<0.01$	No	$P_F=0.97$
Successful cracking attempts value	Yes	$P_F<0.01$	No	$P_F=0.97$
Time duration	No	$P_F=0.84$	Yes	$P_F<0.01$
Time score	No	$P_F=0.96$	Yes	$P_F<0.01$

Time (with instruments inserted) duration	No	$P_F=0.69$	Yes	$P_F<0.01$
Ultrasonic energy score	No	$P_F=0.29$	No	$P_F=0.36$
Ultrasonic energy value	No	$P_F=0.27$	No	$P_F=0.30$
Ultrasonic leakage score	No	$P_F=0.53$	No	$P_F=0.68$
Ultrasonic leakage value	No	$P_F=0.24$	No	$P_F=0.47$

*See Appendix I – Chart 11 for summary of descriptive statistics

The Effect Of Training On the EYESi Simulator

Six participants in the training group had a baseline assessment done in version 2.5. The pre-training assessment of these trainees (n=6) was compared to their post-training assessment to find out what parameters they have improved as a result of training. For Capsulorrhexis Level 8 (Table 26), the training had improved the trainees in the roundness ($P_F<0.01$) and size ($P_F=0.048$) of the rhexis. They also improved their instrument handling skills ($P_F<0.01$) and committed less error in tissue injury ($P_F<0.01$). Most importantly, they performed less radial tears ($P_F<0.01$).

The training also improved the trainees' overall score in the Phaco Divide & Conquer Level 6 (Table 27) when compared to the pre-training stage. The training improved their lens cracking techniques ($P_F=0.01$) and reduced serious errors such as capsule damage by ultrasonic energy ($P_F<0.01$) and posterior capsular tear ($P_F<0.01$).

Table 26. Repeated Measure of ANOVA for Capsulorrhexis Level 8 Variables Of The Pre And Post Training Assessment For The Trained Group

Parameters	Does Training Improves		Learning Effect	
Overall score	Yes	$P_F<0.01$	No	$P_F=0.28$
Average radius of Capsulorrhexis value	Yes	$P_F<0.01$	Yes	$P_F=0.03$
Centering (distance rhexis center to eye center) score	No	$P_F=0.08$	No	$P_F=0.42$
Centering (distance rhexis center to eye center) value	No	$P_F=0.08$	No	$P_F=0.41$
Deviation of rhexis radius from 2.5mm score	No	$P_F=0.09$	No	$P_F=0.58$
Deviation of rhexis radius from 2.5mm value	Yes	$P_F=0.048$	No	$P_F=0.59$
Injured cornea area score	Yes	$P_F<0.01$	No	$P_F=0.19$
Injured cornea area value	Yes	$P_F<0.01$	No	$P_F=0.19$
Maximum radial extension of Capsulorrhexis score	Yes	$P_F<0.01$	No	$P_F=0.76$
Maximum radial extension of Capsulorrhexis value	Yes	$P_F<0.01$	No	$P_F=0.50$
Operating without red reflex duration	Yes	$P_F<0.01$	No	$P_F=0.61$
Operating without red reflex score	Yes	$P_F<0.01$	No	$P_F=0.94$
Roundness of Capsulorrhexis score	Yes	$P_F<0.01$	No	$P_F=0.41$
Roundness of Capsulorrhexis value	Yes	$P_F<0.01$	No	$P_F=0.41$
Time duration	No	$P_F=0.48$	Yes	$P_F=0.02$
Time score	No	$P_F=0.52$	Yes	$P_F=0.02$
Time (with instruments inserted) duration	No	$P_F=0.67$	No	$P_F=0.06$

*See Appendix I – Chart 12 for summary descriptive statistics

Table 27. Repeated Measure ANOVA for Phaco Divide & Conquer Level 6 Of The Pre And Post Training Assessment For The Trained Group

	Does Training Improves:		Learning Effect:	
Overall score	Yes	PF<0.01	No	P_F=0.86
Anterior capsule torn no. Events	No	P_F=0.07	No	P_F=0.08
Anterior capsule torn score	No	P_F=0.06	No	P_F=0.34
Capsule damage by ultrasonic energy no. Events	Yes	P_F<0.01	No	P_F=0.16
Capsule damage by ultrasonic energy score	Yes	P_F<0.01	No	P_F=0.15
Emulsification near the capsule no. Events	Yes	P_F<0.01	No	P_F=0.27
Emulsification near the capsule score	Yes	P_F<0.01	No	P_F=0.77
Non-horizontal instrument insertion/removal no. Events	Yes	P_F=0.03	No	P_F=0.26
Non-horizontal instrument insertion/removal score	Yes	P_F=0.03	No	P_F=0.26
Odometer value	Yes	P_F=0.02	No	P_F=0.09
Posterior capsule torn no. Events	Yes	P_F<0.01	No	P_F=0.82
Posterior capsule torn score	Yes	P_F<0.01	No	P_F=0.68
Successful cracking attempts score	Yes	P_F=0.01	No	P_F=0.13
Successful cracking attempts value	Yes	P_F=0.01	No	P_F=0.13
Time duration	No	P_F=0.42	No	P_F=0.07
Time score	No	P_F=0.47	No	P_F=0.06
Time (with instruments inserted) duration	No	P_F=0.57	No	P_F=0.09
Ultrasonic energy score	No	P_F=0.82	No	P_F=0.06
Ultrasonic energy value	No	P_F=0.89	No	P_F=0.05
Ultrasonic leakage score	No	P_F=0.28	No	P_F=0.14
Ultrasonic leakage value	No	P_F=0.08	No	P_F=0.12

*See Appendix I – Chart 13 for summary of descriptive statistics.

Skill Retention After The Training

The post-training assessment was done for each trainee within 3 weeks after he or she completed the proficiency based training curriculum. Despite the fact that all the trainees (n=10) achieved the proficiency level requirement of the curriculum, their performance in the post-training assessment was not as good. The three scores they passed for each module during the training were compared with the three scores in the post-training assessment. In both the Capsulorrhexis ($P_F<0.01$, Table 28) and the Phaco Divide and Conquer ($P_F<0.01$, Table 29) modules, the trainees performed significantly worse compare to their best achievement. The main parameter that the trainees lost over time was the roundness of rhexis in the Capsulorrhexis module. Likewise, the main parameter that the trainees failed to maintain in the Phaco Divide and Conquer module was the posterior capsular torn rate.

Table 28. Repeat Measure ANOVA of Capsulorrhexis Level 8 Variables Of The Proficiency Score Versus The Post Training Assessment In The Trained Group

Parameters	Is the skill retained?		Learning Effect:	
Overall score	No	$P_F<0.01$	No	$P_F=0.33$
Average radius of Capsulorrhexis value	Yes	$P_F=0.48$	No	$P_F=0.07$
Centering (distance rhexis center to eye center) score	Yes	$P_F=0.10$	No	$P_F=0.76$
Centering (distance rhexis center to eye center) value	Yes	$P_F=0.11$	No	$P_F=0.80$
Deviation of rhexis radius from 2.5mm score	Yes	$P_F=0.39$	No	$P_F=0.26$
Deviation of rhexis radius from 2.5mm value	Yes	$P_F=0.14$	No	$P_F=0.06$
Local irregularity of Capsulorrhexis (spikes) score	Yes	$P_F=0.63$	No	$P_F=0.15$
Local irregularity of Capsulorrhexis (spikes) value	Yes	$P_F=0.63$	No	$P_F=0.15$
Maximum radial extension of Capsulorrhexis score	Yes	$P_F=0.33$	No	$P_F=0.38$
Maximum radial extension of Capsulorrhexis value	Yes	$P_F=0.86$	No	$P_F=0.10$
Operating without red reflex duration	Yes	$P_F=0.30$	No	$P_F=0.34$
Operating without red reflex score	Yes	$P_F=0.27$	No	$P_F=0.29$
Roundness of Capsulorrhexis score	No	$P_F<0.01$	No	$P_F=0.41$
Roundness of Capsulorrhexis value	No	$P_F<0.01$	No	$P_F=0.41$
Time duration	Yes	$P_F=0.97$	No	$P_F=0.28$
Time score	Yes	$P_F=0.92$	No	$P_F=0.26$
Time (with instruments inserted) duration	Yes	$P_F=0.72$	No	$P_F=0.30$

*$P_F \geq 0.05$ is an indication of skill retention

** See Appendix I – Chart 14 for summary of descriptive statistics.

Table 29. Repeat Measure ANOVA of Phaco D&C Level 6 Variables Of The Proficiency Score Versus The Post Training Assessment In The Trained Group

Parameters	Is the skill retained?		Learning Effect:	
Overall score	No	$P_F<0.01$	No	$P_F=0.51$
Anterior capsule torn no. Events	Yes	$P_F=0.15$	No	$P_F=0.63$
Anterior capsule torn score	Yes	$P_F=0.15$	No	$P_F=0.63$
Emulsification near the capsule no. Events	Yes	$P_F=0.43$	No	$P_F=0.60$
Emulsification near the capsule score	Yes	$P_F=0.32$	No	$P_F=0.67$
Injured cornea area score	Yes	$P_F=0.38$	No	$P_F=0.32$
Injured cornea area value	Yes	$P_F=0.38$	No	$P_F=0.32$
Odometer value	Yes	$P_F=0.67$	No	$P_F=0.69$
Posterior capsule torn no. Events	No	$P_F=0.02$	No	$P_F=0.31$
Posterior capsule torn score	No	$P_F<0.01$	No	$P_F=0.26$
Successful cracking attempts score	No	$P_F=0.03$	No	$P_F=0.88$
Successful cracking attempts value	No	$P_F=0.03$	No	$P_F=0.88$
Time duration	Yes	$P_F=0.82$	No	$P_F=0.10$
Time score	Yes	$P_F=0.82$	No	$P_F=0.10$
Time (with instruments inserted) duration	Yes	$P_F=0.99$	No	$P_F=0.12$
Ultrasonic energy score	Yes	$P_F=0.12$	No	$P_F=0.25$
Ultrasonic energy value	Yes	$P_F=0.29$	No	$P_F=0.11$
Ultrasonic leakage score	Yes	$P_F=0.24$	No	$P_F=0.28$
Ultrasonic leakage value	Yes	$P_F=0.26$	Yes	$P_F=0.03$

*$P_F \geq 0.05$ is an indication of skill retention

*See Appendix I – Chart 15 for summary of descriptive statistics.

DISCUSSION

Establishing Construct and Face Validity

The Irish College of Ophthalmologists purchased an EYESi cataract surgical simulator for training purposes. This simulator appeared to be a sophisticated machine designed in such a way to recreate the setup of phacoemulsification in the theatre. It also has built-in metrics to measure the performance of the operator in pre-determined parameters. In order for the metrics to be useful in determining the operator's performance, it has to demonstrate reliability and validity.

Reliability means the consistency of a set of measurements.[58] It can be sub-divided into several sections including inter-rater and test/retest reliability. A test with good inter-rater reliability will have the same measurement if different operators demonstrate the same skills. A test with good test/retest reliability will show similar scores when the same person takes the same test repeatedly.

Validity is another important aspect of a set of measurements. In psychometrics, validity refers to the degree to which evidence and theory support the interpretations of test scores.[59] In this section of the study, we are interested to see can the EYESi simulator be used as a training tool for learning phacoemulsification. In order to achieve this, it has to demonstrate face validity and construct validity. Face validity is a subjective view of the content of the measurement in relation to the intent. All the expert and trainee surgeons in this study supported the usefulness of this simulator. On the other hand, construct validity is an objective analysis to support its existence. Construct validity means the ability of the instrument to measure the construct that it is intended to measure.[60] In this study, we want to measure the operator's surgical skill level. Can the EYESi simulator differentiate people with different surgical skill in real life? If it can, then the difference in score can be assumed to reflect the difference in surgical skills level, consequently, training on simulator to achieve higher score would mean gaining surgical skills.

Mahr et al showed experienced surgeons did better than the residents in Anti-tremor and Forceps modules in the EYESi. In contrast to Mahr's study, there were no significant difference between the experienced surgeons and the trainees in this study. In Mahr's study, software version 2.2 was used, 3 experienced surgeon versus 11 trainees (n=14), and none of the participants had any previous experience on the simulator. This study used version 2.4, 15 experienced surgeons versus 18 trainees (n=32). A major difference is that the 18 trainees in this study had an average of 2 hours of previous simulator training. In the skill modules, the tasks are relatively simple therefore even a short training period can increase the score dramatically. So the lack of significant difference between these two groups could be due to previous training.

However, even with previous training in the trainee group, the experienced group still performed significantly better than the trainees in the two important steps of cataract surgery. No published data was found in relation to the construct validity of these two modules. In Capsulorrhexis

Level 8, the expert group performed significantly better than the trainees in the total score (P_F=0.02), with less time (P_F=0.04) and less radial extension (P_F=0.03). Radial extension is the most undesirable error when performing capsulorrhexis in real surgery. The fact that the simulator picked up this particular difference indicated a good discerning power. In Phaco Divide & Conquer Level 6, the expert group performed significantly better than the trainees in the total score (P_F=0.03), less time (P_F=0.04), less emulsification near the capsule (P_F=0.01) and less anterior capsular torn event (P_F=0.04). Anterior capsular tear is a result of emulsifying near the edge of the rhexis. This is also a common mistake by the trainees in the operating room due to failure to visualize the edge of the rhexis when sculpting.

The standard deviations in both groups were high in all parameters. (Figure 1-8) Wide standard deviation indicated a wide range of skill level within each group. Again this would reflect the reality that there is a mixed level of skills even among the expert group. Another reason for the wide standard deviation is related to the fidelity of the simulator. One common complaint from the participants was that the graphic simulation was not realistic. In version 2.4, the problem with the Capsulorrehxis module was the flap of the rhexis behaved as if there was not viscoelastic in the anterior chamber. It waved like seaweed in the water instead of being stationary like in real surgery. This was unexpected to experienced surgeons and therefore some of them could not achieve a good score. Another reason for a wide range of scores was that the simulator gave a substantial proportion of the score to the roundness of the rhexis. A perfectly round rhexis, although desirable, is not essential in most cataract surgery except for using accomodative intraocular lens. In the Phaco Divide and Conquer module, the lens behaved with too much mobility. It rotated too easily and therefore it was hard to perform sculpting and cracking.

After the assessment, the participants in both the expert and trainee groups were asked for their opinions on using the simulator as a training tool. The participants in this study agreed that the simulator could benefit surgical training (100%), reduce the learning curve on patients (90%) and decrease intraoperative error (83%). Yet, only 20% of the participants thought that trainees should be trained on the simulator until proficiency is achieved before starting to operate on patients. This reflected that the concept of pre-training was not prevalent among the consultants and junior doctors. The simulator cannot and will not replace surgical learning achieved by operating on patients. The ideal is to use simulator as a platform for learning important surgical concepts and acquiring appropriate surgical skills before operating on patients. For example, instead of stuggling to orientate the direction of the instrument movements when operating on patients for the first few times, the principle of the fulcrum effect and the hand coordination skills can be effectively and safely learned on a simulator.

Setting Proficiency Level And Designing A Training Curriculum

Proficiency level is a standard of performance that trainees are required to reach in order to demonstrate the acquisition of skills. The proficiency level can be determined once the expert group demonstrates significantly better performance on the simulator compared to the trainees. The difference in achievement between the two groups can be assumed to be due to the different level of surgical skill ability. The expert group possesses the necessary microsurgical skills for them to perform better than the trainees in the virtual surgical environment. Therefore, by setting the proficiency level based on the expert group's score, the trainees will have to acquire new skills in order to reach the target score.

The proficiency level is the minimum requirement the trainees need to attain. The design of this assessment (Section I) did not allow the experts to reach the maximum potential on the simulator. They had only 5 attempts for each module. Therefore, simply averaging the scores of the expert group resulted in a very low target score. The proficiency level should not be too low because the training may not be adequate. On the other hand, it should not be too high because the trainees would be discouraged and the cost of providing the training would be very high. It should be realistic and achievable by all trainees who put in the effort to learn.

The curriculum is designed to train the basic surgical maneuver necessary for performing phacoemulsification. The core skills to obtain are steady control of one inside the eye such as capsulorhexis forceps and two instruments inside the eye such as phaco tip and Drysdale. The common mistake for one instrument operation is not utilizing the free second hand to enhance steadiness. Instrument shake can be greatly reduced by placing the second hand on the operating hand for an extra support.

Two- handed operation adds enormous complexity to the instrument maneuvering. Due to the nature of the shape of the instrument, the mechanics of movement are very different between the angled and straight instruments. For example, in order to move the tip in the horizontal plane, the angled instrument moves by rolling with the finger of the instrument holding hand while the straight instrument moves by movement of the wrist of the instrument holding hand. Many trainees got lost in space orientation in the beginning with tension in the shoulder, wrist and finger while holding the instrument too tightly. The most common mistake during training of two-handed operation is trying to move two instruments at the same time. Because both hands require different movement due to the shape of the instrument, it is very easy to become confused. The solution is to train moving only one hand at a time before moving the other. Eventually the skill for two handed operation will become more integrated and the trainees can focus on the task rather than on the hand movement. Another advantage of moving one hand at a time is that while moving one instrument, the other instrument can help to maintain the red reflex by holding the eye in a fixed position to resist movement cause by the other instrument.

The most common mistake in the Cracking & Chopping is to move the instruments in a circumferential motion. In Level 1 and 2, the position of the sphere does not move when the tips become disengaged. However, in Level 3 and 4, the positions of the sphere will bounce back to the starting point if the tip becomes disengaged at any point before completing the task. This happens because moving the instrument in the horizontal plane with the corneal incision as the pivot point produces a circular movement. This motion inevitably causes the tip to slip out of the sphere. To move in a straight line, the tip not only has to move horizontally but also longitudinally. That means inserting or withdrawing in addition to pivoting the instrument along the corneal incision depending on the direction desired.

Another challenge in the Cracking & Chopping module is to avoid shifting the barbell away from its original position. In Level 1 and 2, the position of the objects is fixed. At Level 6 and 7, the position of the barbell will shift if any torque force is applied to the barbell. This happens when the tips of the instruments move past the imaginary line along the bar of the barbell. In physical terms, this means the trainee inserted too much of the instrument into the eye. In Level 7 and 8, not only the spheres at either end will bounce back if the tip slips out, but also the barbell will move if any torque force is applied. So to complete these two levels successfully, the trainee would have to master the skill of moving two tips in a straight line both away and toward each other.

The understanding and controlling of phacodynamics is another core skill emphasized in this curriculum. The parameters on the phaco control panel emulate the AMO machine. The parameters that can be altered are bottle height, vacuum level, flow pump or vacuum pump, rise time, and ultrasonic energy level, continuous or pulsed. The trainees would learn the theoretical and clinical indications of setting and changing the parameters. They also would understand that the setting of the aspiration and ultrasonic energy level are the maximum allowed level but the actual level is achieved by using the foot pedal. The concept of ultrasonic energy leakage and wastage is emphasized in this module, as they are associated with a heavy penalty if not used effectively. The method of determining how much ultrasonic energy to use is by visual feedback on the disappearance of the lenticular material since tactile feedback is minimal for this surgery. On the LCD screen inside the eyepiece, the trainee can also visualize the numeric value of each parameter and learn to control the level by varying the foot position.

Summary

In summary, the EYESi simulator training curriculum designed for this study is structured and proficiency based. The aim is to train the psychomotor skills, depth and spatial judgment, controlling of phacodynamics and awareness of potential surgical complications. It is divided into Capsulorrhexis and Phacoemulsification components with 5 courses for each component. The proficiency level is based on the performance of 10 experienced Irish ophthalmic surgeons. The trainees have to reach proficiency level on three consecutive occasions in each task before advancing to the next level. The end point for this training is completion of the Capsulorrhexis Level 8 and Phaco Divide & Conquer Level 6 on the EYESi simulator.

In slide 65 (Title: Fluidic Circuit, Figure 14), the function of the foot pedal is clearly visualized. As the surgeon pushes his/her foot down into position 1, it opens the pinch valve in the phaco machine to facilitate irrigation of fluid out of the silicon sleeve. In position 2, the pump is activated. This leads to the aspiration of fluid into the phaco tip. The strength of the current is proportional to the foot position. In position 3, the piezoelectric crystal is activated to create oscillation at the phaco tip.

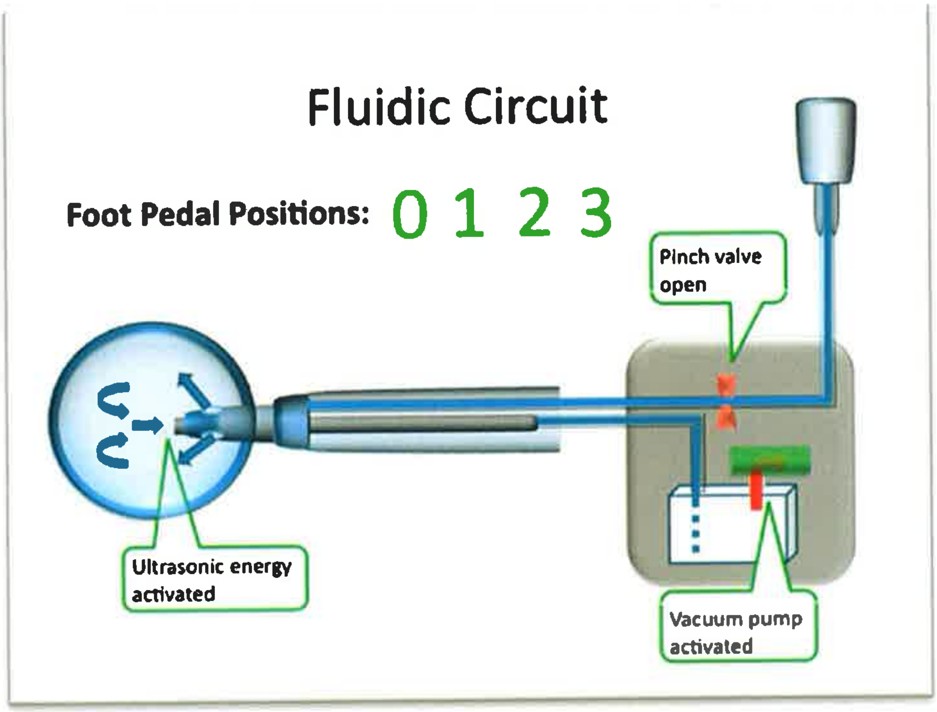


Figure 14. Slide 65 - Explaining how the foot pedal controls the phaco machine and its effect in the eye

After the lecture, the audience answered two surveys. The first survey aimed to establish the face validity of the content (Table 8). The audience found the lecture had a clear objective, and was useful for gaining understanding in cataract surgery. The animation helped to clarify principles of complex surgical procedures and was interesting. All of the audience would recommend this lecture to other trainees. The lecture was delivered in just 2.5 hours, which is a relatively short period of time. Many of them felt more sessions are needed to consolidate the learning.

The second survey aimed to determine the trainees' perceived competence in learning the lecture material and performing cataract surgery. The perception of competence is an important element for motivation and goal attainment according to the Self-determination Theory.[61] A didactic curriculum should provide sufficient knowledge and clarity on a subject in order to convey a sense of confidence for the learners in achieving the goal. This lecture material has successfully imparted a sense of confidence to the trainees (Table 9). They felt capable of achieving the goal of learning cataract surgery. However, this lecture does not perform as well in imparting confidence in facing the challenges of performing cataract surgery. The content of this lecture focuses on what are the right things to do and what to avoid. It does not contain information on how to rescue a difficult situation. Therefore, the trainees did not feel confident in facing the challenges in performing cataract surgery. The rescuing of difficult situations is beyond the scope of this lecture material.

Summary

In summary, learning to perform surgical procedures requires effective transfer of both knowledge and operative skills. Minimally invasive surgery such as phacoemulsification demands knowledge in the interaction and manipulation of instruments in addition to the knowledge in anatomy and surgical procedures. Learning from text or diagrams alone is often inadequate to highlight the simultaneity of multiple operative maneuvers. Surgical videos are limited to the surgical field and fail to show the interaction of the entire surgical environment. The use of 3-D animation can provide an additional facet of knowledge transfer because it enables trainees to 'see' instead of 'imagine' how things are done. In this study, the content of the curriculum was validated by 5 ophthalmic consultants and 24 trainees. All in attendance agreed on the use of 3D animation as an effective tool when teaching complex surgical procedures, in addition to texts, diagrams and videos. It is interesting to watch and can help trainees to consolidate important surgical concepts by visualizing the simultaneous co-ordination of hand and foot movement for controlling surgical instruments.

EYESi Simulator Training Sessions

When conducting this training, I did not restrict the time allocated for each session except when the training session was staggered where I had booked each training session two hours apart. The trainee can terminate a training session at any time. Fatigue is the most common reason for terminating a session. Fatigue can be both mental and physical. Many of the training sessions took place after a full working day in the hospital. The concentration required to achieve the target score is enormous especially when consistency of performance is paramount for passing each level. The mental and physical processes during a simulator session can be explained by Fitts and Posner's Three Stages of Motor Skill Acquisition: cognition, integrating and automation.[35] In the cognition phase, the trainee became acquainted with the instrument handling and task requirement. There are two basic instrument shapes: straight (i.e. phaco tip) and angled (i.e. cystotome and capsulorrhexis forceps). These instruments enter into the eye through incisions on the cornea. In order not to tilt the eye during the operation, the trainees need to maneuver the instruments using the corneal incision port as the pivoting point. The fulcrum effect of the corneal incision port is the most fundamental principle of instrument handling for intraocular surgery. Once the trainees understood the mechanics of instrument movements, they need to understand the procedural requirement.

The integration phase is when the mental understanding is converted into action. The fulcrum effect of the instrument is already hard to execute with direct visualization. The use of a microscope broke the direct visualization of hand movement making the task more difficult to complete. The time of red reflex loss is a good parameter to measure the trainees' ability to maneuver the instruments properly. The red reflex is lost when the eye is tilted and the only place the instrument causes eye movement is at the entry point. It is a natural tendency to move the whole instrument to the left when the trainee intends to move the tip to the left. However, because of the fulcrum effect, the trainee should move the instrument to the right (i.e. opposite direction outside the eye) so the tip of the instrument will move to the left. The control of movement becomes more complicated when both hands are moving at the same time. Physical fatigue develops quickly in the beginning when the trainee tends to grip the instrument tightly, locking the wrists, and shoulders. As a trainer, I quite often have to check the posture of the trainees and remind them to relax. Eventually, the trainees learn to hold the instrument with just enough tension to ensure steadiness and flexibility. Another source of physical fatigue is ocular strain due to excessive accommodation. This can be observed by the change of the focusing plane on the flat screen monitor. As the trainees progressed in the training, these physical tensions gradually diminished.

The automation phase is when the individual component of the learned material is consolidated. Repeated practice allows the new information to be transferred into longer-term memory. The curriculum uses a gate that not only requires trainees to attain above a certain score but also have it repeated on three consecutive occasions. If, for example, the score reached the proficiency level twice but failed it on the subsequent attempt, the trainee has to start from scratch. The requirement to be consistent ensures the automation process occurs. One interesting observation was the trainees' anxiousness when they have achieved the proficiency twice. As the next attempt was so important to determine if they would advance to the next level or repeat the whole procedure again, the performance usually was negatively affected. The requirement for three successful consecutive achievements focuses the trainees to pay attention to detail in order to obtain consistent good performance. The mental and physical requirement to perform well in the simulator is high and after a two hour session, the trainees were usually exhausted.

Statistics of Training Sessions

In this study, the training period to complete this curriculum was 64 days (SD 25.4 days) or 9 weeks (Table 10). There were a wide range of training periods among the trainees that varied from 26 days to 99 days. Participation in this study was completely voluntary; therefore, no restriction was stipulated on how quickly the training should be finished. The wide range of the training period reflects the realistic availability of the trainees for simulator training. Many reasons affect the training period including annual leave, on-call duties, studying for exams and social obligation. The mean number of training session required to complete the curriculum is 12.2 (SD 2.4, range 9-15). The frequency of attending a session was dependent on their personal schedule and simulator availability. The time required was 20.2 hours (SD4.7 hours, range 14.5 -27.3 hours). The average time for each session was 99.4 minutes (SD 34.9 minutes).

Overall, these figures demonstrated the feasibility of implementing this curriculum to the wider population. All the trainees achieved proficiency level three consecutive times in each task. There is no significant correlation between the length of the training periods to the total time required to complete the curriculum ($p=0.65$). The reason for the lack of correlation may be due to the fact that each of the 41 tasks in the curriculum is short and can be achieved with moderate effort. Once a task is finished, it does not need to be repeated again. Therefore each training session is relatively independent of the previous one. We can thus surmise that the frequency of attending a session is not a factor that alters the quality of skill acquisition within the training period in this study. From the point of view of pre-training the trainees before operating on patients, two months spent in simulator training first will not severely impede a trainee's progress in surgery. On the contrary, the time spent in simulator training could enhance the trainees' surgical learning experience.

The duration of training (Table 10) for each individual varies widely ranging from 9 sessions to 15 sessions and from 14.5 hours to 27.3 hours. The attempts to reach the proficiency level ranges from 300 to 603. This data supports the observation that there are individual differences in the learning curve. The use of the number of cases or time to determine the skill level does not truly reflect one's ability. Gifted trainees can achieve proficiency sooner than the average trainees. Therefore, using the nunber of surgical cases done as a measure of skill level is not an accurate reflection of one's ability. However on the other hand, as a trainer, it is gratifying to see that given enough time and resources, everyone can reach the proficiency level.

In this curriculum, trainees were required to pass the proficiency score three times consecutively in order to move to the next level. This is based on Ericsson's model of deliberate practice in which expertise is a result of purposeful repetition until reproducible performance is reached.[53] The number of repetitions required determined the amount of time and attempts needed to complete the curriculum. The mean total simulator time for three repetitions is 13 hours 44 minute (100%), for two repetitions is 8 hour 47 minutes (64%) and for one is 4 hours and 2 minutes (30%). The session time is longer than the simulator time because part of it was used for explaining surgical principles and short breaks.

This is the first time data for EYESi simulator training sessions has become available. To make a curriculum practical and feasible, the ICO would need to evaluate the resources available for training. With this information, the duration of the curriculum can be amended accordingly. If a shorter course is required, the gate can be set to 2 or 1 to reduce the time. Another way to alter the time required to finish a course is to look at individual modules in Table 12. Capsulorrhexis modules take up most of the training time (44.2%), followed by Phaco Divide & Conquer (24.8%), Bi-manual (6.9%), Navigation (6.9%), Anti-tremor (3.5%), Cracking & Chopping (3.08%) and Phaco training (2.23%). In Capsulorrhexis, it is not necessary to go through the entire 8 levels to learn to do a good rhexis. If the curriculum eliminates the first 4 levels, it would save 21% of the total time or 2.8 hours per trainee. This of course, is only an estimate, because there is no data to show the effect of skipping lower levels on learning a task. Another way to alter the curriculum is to look at the number of attempts for each individual module in Table 13. A small amount means it is easy to do, therefore, it can be eliminated from the course to save time. Ultimately, the final proficiency level should not be compromised, but the means of getting there can be flexible.

Correlation of Aptitude Tests to Learning Curve

The visual spatial ability of the participants was measured with card rotation, cube comparison and map planning tests.[57] The cube comparison test showed significant correlation with the number of sessions ($r=-0.639$, $p=0.047$, Figure 9), total simulator time ($r=-0.71$, $p=0.021$, Figure 10), and attempts required to complete the PBP curriculum ($r=-0.736$, $p=0.015$, Figure 11). The map-planning test also correlated significantly with the number of attempts ($r=-0.722$, $p=0.018$, Figure 12). In other words, a higher cube comparison score is associated with a steeper learning curve where less time, and attempts are required to finish the curriculum. Both the cube comparison and map planning together form a good predictor for the number of attempts required by a trainee to achieve the proficiency level.

The cube comparison test has also been found to correlate with the learning curve on the endoscopic virtual reality simulator (GI Mentor II VR simulator, Simbionix, USA, Cleveland, OH).[62] Ritter et al suggested that the reason the cube rotation correlate with learning the endoscopic procedure is because the ability to mentally manipulate a 3-dimentional recreation of a 2-dimentional image corresponds with the ability to mentally navigate in the colons or duodenum with a flexible endoscope while watching the screen. Unlike the endoscopic simulator, the participant is seeing a stereoptic image through the binocular microscope in the EYESi simulator. There is no need to convert a 2-dimentional image into 3-dimentional spaces. Nevertheless, higher aptitude test scores were associated with a shorter learning curve in the EYESi simulator. Participants with higher mental ability for orientation in space can learn microscopic surgery quicker.

EYESi Simulator Assessments

Trained Group - Pre and Post Training Assessment

The main objective of simulator training is to acquire microsurgical skills outside the operating theatre. When the post-training assessment of the trained group was compared to their pre-training assessment, the Capsulorrhexis (PF<0.01, Table 26) and Phaco Divide & Conquer (PF<0.01, Table 27) showed significant improvement. This demonstrated that these skills were developed as a result of the training. To further evaluate the effect of training, the post-training assessments of the trained group were compared with the second assessment of the non-training group.

Trained Group Versus Non-Training Group

It is not a surprise that the trained group performed significantly better than the non-trained group on the overall score of every module in the second assessment (Table 18-25). The significance of this finding is not on the overall score but on the analysis of the individual parameters. In the data analysis, both the score and physical measurement for each parameter were analyzed, but only the analysis of the physical measurements will be included in the discussion. The reason for this is because the score for each parameter is arbitrarily pre-set by the manufacturer.

In the simple tasks modules such as Navigation Level 3, Anti-Tremor Level 3 & 4, Forceps Level 4, Bi-manual Level 4 and Chopping & Cracking Level 4 the target achievements were not significantly different in these two groups. This is because the goal is easy to attain. What made the overall score worse in the non-trained group was the accrued penalty points because of the lack of efficiency, excessive tissue injuries, and poor instrument handling. Operating without red reflex parameter is an important indicator for the participant's ability to move the instruments without tilting the eye. In order to maintain the red reflex during operation, the participant needs to understand the fulcrum effect at the entry point and have the hand-eye coordination to execute fine movements. The longer duration of operating without red reflex in the non-trained group reflects the lack of insight and skill to overcome the fulcrum effect. The propensity to injure the cornea and lens in the non-trained group indicates the lack of depth perception and fine motor control. The intraocular space for cataract surgery is very small. The average distance between the endothelium to the capsule is only 3mm. A given task should not be accomplished at the expense of tissue injury. The odometer value is a measure of economy of movement. The trained group made significantly more purposeful movements that enabled them to achieve the goal more effectively.

In complex procedural modules such as Capsulorrhexis Level 8 and Phaco Divide & Conquer, the trained group not only received significantly less penalty points from making errors, but more importantly, they attained significantly higher target achievements. This means that the trained group is more successful in performing a good capsulorrhexis and phacoemulsification. The target achievement in the Capsulorrhexis Level 8 is based on the site, size and shape of the rhexis in addition to the avoidance of spikes and radial tear. While there were no significant differences in the site

($P_F=0.10$) and size ($P_F=0.07$) of the rhexis between the two groups, the trained group achieved better roundness of the rhexis ($P_F<0.01$) as well as lower incidence of spike ($P_F=0.03$) and radial tear ($P_F<0.01$).

In Phaco Divide & Conquer, the trained group achieved higher successful cracking attempts ($P_F<0.01$) and lower capsule damage by ultrasonic energy ($P_F=0.01$) than the non-trained group. Cracking the large lens into 4 quadrants after sculpting is the quintessence of the 'divide & conquer' technique. Without performing the cracking successfully, the phaco time will be prolonged resulting in higher ultrasonic energy usage and higher risk of posterior capsular tear.

There are, however, some parameters where the training did not result in significant differences. The ultrasonic energy usage ($P_F=0.27$) and leakage ($P_F=0.24$) were similar between the trained and non-training group. The phaco foot pedal control is an important aspect of training in the PBP curriculum. The failure to retain this skill means that the curriculum should reinforce the training of ultrasonic energy control. Another parameter the trained group failed to maintain was avoiding a posterior capsule tear ($P_F=0.06$). Even though the P_F value is very close to <0.05, the trained group should not have made any posterior tears in three attempts. Again, future training should reinforce the avoidance of capsular tear.

Retention Of Skills

Retention of skill is an important aspect of training. During the training period, all trainees reached their best scores because they had as many attempts as they needed to reach proficiency. When these scores were compared with the post-training assessment within three weeks of their last training session, there were no significant differences in all the simple skill-training modules. This means that the skills learned in the simple training modules are retained. In contrast, the score was significantly lower in the Capsulorrhexis (Table 28) and Phaco Divide & Conquer (Table 29) modules. This indicates that the skills they developed were not retained after only just three weeks. These two tasks are complex surgical simulations that involve many steps that require thorough understanding of the surgical principles and careful execution of each step. For simple tasks the skills can be retained for longer but for the more complex surgical procedures the skill retention is short. The current proficiency standard did not allow enough consolidation of skills in these two modules. In future curriculums, it would be advisable to reduce the simple task module and allocate more time for the complex modules.

Summary

In summary, the trained group consistently attained higher target achievements while causing less tissue injuries, committing less blunders, maintaining longer red reflex, and had better economy of movement. The proper techniques developed in the simple skill module can be maintained even in the more complex procedural modules. These parameters reflect the acquisition of pertinent skills from the training, which were shown to be the characteristics of the expert group in the construct validity study. Despite the lack of the randomized control trial for virtual reality to operating room (VR to OR) study, the value of simulator training is evident as shown in this study. The importance of pre-training is again highlighted here. The virtual reality modules in the EYESi simulator can facilitate training the novice surgeons on many important surgical principles and microscopic maneuvering skills without putting patients at risk.

CONCLUSION

Pre-training of inexperienced junior doctors can ensure the acquisition of pertinent knowledge and psychomotor skills before making his or her first incision into a real patient. This is a perfectly logical and rational thing to do but currently seldom done in cataract surgery training. The main reason is the lack of validated metrics to measure the competence of a trainee. If this was established, a training body like the Irish College of Ophthalmologists could have guidelines that clearly define the level of readiness a trainee should attain before operating on a patient.

In the Halstedian method of training, an experienced surgeon supervises a novice until he or she is competent to operate independently. Since the overall responsibility rests with the master surgeon, the trainee generally concentrates on acquiring new operating skills during the procedure. In other words, the trainee is practicing on patients and it is up to the master surgeon to ensure patients' safety during this procedure. The number of patients operated on is used as a partial measurement of competency. Without a doubt the Halstedian method of training has worked very well to produce competent surgeons for over a hundred years. However, as the current clinical environment demands putting patient safety first by reducing medical errors, it therefore should no longer be permissible for an untrained doctor to operate on patients, thus potentially increasing their risk of complications.

The dilemma is that nothing feels and behaves like the human biological tissue. Without a process of gaining experience by operating on a patient no one can become a truly competent surgeon. The solution for improving patient safety while training novice surgeons is to ensure adequate pre-training on the necessary knowledge and psychomotor skills before operating on a patient, so that when they do operate on a patient for the first time, they have more mental capacity to focus on managing the surgical environment as a whole. Complications happened most when the trainees failed to recognize an imminent danger.

Virtual Reality surgical simulator offers an additional tool to the wet lab for pre-training novice surgeons. The major advantage of VR simulator over the wet lab is a built-in metric system that measures the physical parameters and gives immediate feedback to the trainees. In this study, EYESi simulator demonstrated construct validity in two surgical simulations, the capsulorrhexis and phacoemulsification, by measuring relevant parameters that can differentiate skill levels. Therefore, it is possible to set a proficiency level based on the expert surgeons' performance and use it as the gold standard. This study also demonstrated that trainees showed measurable improvements on the simulator performance with training. By practicing on the simulator to reach the set proficiency level, trainees developed appropriate psychomotor skills, including hand-eye coordination and proper instrument handling techniques. The occurrence of serious intra-operative errors and tissue damage in the simulation was reduced. However, the skills learned in the surgical simulation can be quickly forgotten therefore the trainee should practice on the simulator regularly until the skills are consolidated.

For the first time, a validated didactic and skill acquisition curriculum for cataract surgery based on competency rather than quantity is available to the Irish College of Ophthalmologists. The information collected from this pilot study provides the basis to design a structured cataract training curriculum for the Irish trainees. Proper training is the key element in reducing medical errors and pre-training of the novice surgeons in a controlled, non-risk environment to reach an acceptable level of proficiency in both knowledge and skill should be a prerequisite before operating on a patient.

The goal of pre-training is not and cannot replace the learning experience gained in the operating theatre but rather enhances it. A well-prepared trainee will reduce intra-operative errors on patients and gain more from each operative experience. Trainees become more confident when they know what to expect and how to do the procedure. This in turn alleviates the stress level of both the trainees and the master surgeons during the operation. A competent trainee is likely to be allowed to do more independently by the master surgeon. Ultimately a better training program with clear guidelines on the proficiency level can be achieved with the VR stimulator. This would not only improve patient safety, but would also result in a mutually gratifying experience for both the trainees and the trainers.

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APPENDIX I

Summary statistics for EYESi simulator data

Chart 1. Summary Statistics by Trainee and Expert for Capsulorrhexis Variable

	Expert		Trainee	
Variable	M	SD	M	SD
Time 1				
score	55.57	33.629	39.72	30.383
Time (time)	02:56.6	00:52.6	03:51.0	01:40.8
Roundness of Capsulorrhexis (value)	0.51	0.3	0.44	0.316
Centering (distance rhexis center to eye center) (value)	0.29993	0.160471	0.42956	0.198877
Deviation of rhexis radius from 2.5 (value)	0.20769	0.214766	0.27803	0.219713
Maximum radial extension of Capsulorrhexis (value)	3.0693	0.45456	3.3022	0.42272
Incision stress (value)	0.8028	1.93708	1.1254	2.42313
Time 2				
score	43.93	31.252	28.28	27.559
Time (time)	02:25.9	00:47.6	03:26.3	01:59.7
Roundness of Capsulorrhexis (value)	0.43	0.383	0.23	0.232
Centering (distance rhexis center to eye center) (value)	0.32988	0.161934	0.44184	0.314338
Deviation of rhexis radius from 2.5 (value)	0.26261	0.184998	0.2977	0.293616
Maximum radial extension of Capsulorrhexis (value)	3.2607	0.36184	3.4694	0.49014
Incision stress (value)	0.06	0.133	1.34	3.818
Time 3				
score	53.29	32.537	34.67	27.016
Time (time)	02:09.9	00:33.6	03:04.6	01:20.1
Roundness of Capsulorrhexis (value)	0.46342	0.406122	0.30075	0.273641
Centering (distance rhexis center to eye center) (value)	0.38886	0.194516	0.39559	0.159825

Deviation of rhexis radius from 2.5 (value)	0.180614	0.153048	0.270803	0.262522
Maximum radial extension of Capsulorrhexis (value)	3.1164	0.38737	3.3567	0.42328
Incision stress (value)	0.8	2.372	0.85	1.718
Time 4				
score	52.64	32.848	28.78	29.317
Time (time)	02:03.6	00:30.8	02:56.6	01:14.5
Roundness of Capsulorrhexis (value)	0.46648	0.357562	0.21461	0.265945
Centering (distance rhexis center to eye center) (value)	0.27391	0.180125	0.39468	0.186536
Deviation of rhexis radius from 2.5 (value)	0.23016	0.214543	0.3503	0.276709
Maximum radial extension of Capsulorrhexis (value)	3.1336	0.48033	3.4961	0.4892
Incision stress (value)	0.98	3.35	0.49	1.044
Time 5				
score	54.86	31.654	48.83	28.741
Time (time)	02:11.6	00:38.3	02:37.9	01:26.5
Roundness of Capsulorrhexis (value)	0.46368	0.358382	0.54872	0.305421
Centering (distance rhexis center to eye center) (value)	0.3333	0.21907	0.3254	0.16595
Deviation of rhexis radius from 2.5 (value)	0.155405	0.114139	0.349294	0.333939
Maximum radial extension of Capsulorrhexis (value)	3.074	0.3327	3.186	0.4771
Incision stress (value)	0.8093	2.69406	1.4742	4.48747

Chart 2. Summary Statistics by Trainee and Expert for Phaco Divide & Conquer Variables

	Expert		Trainee	
Variable	M	SD	M	SD
Time 1				
score	58.67	28.637	51.17	23.357
Time (time)	03:57.1	01:12.4	05:06.7	02:14.4
Incision stress (value)	5.401	9.9117	21.154	59.3205
Iris contact (value)	0.1509	0.30063	0.8183	1.7578
Odometer (value)	1163.227	569.0143	1430.178	601.0824
Emulsification near the capsule (# events)	7.6	3.291	8.5	3.073
Ultrasonic energy (value)	569.18	345.7403	540.372	228.6512
Damaged zonular fibers (value)	0.33	0.759	2.87	7.973
Posterior capsule torn (# events)	0	0	0.06	0.236
Anterior capsule torn (# events)	0	0	0.22	0.428
Time 2				
score	59.53	27.145	53	26.944
Time (time)	03:28.1	01:16.7	04:03.3	01:04.6
Incision stress (value)	3.896	8.9902	17.36	33.3628
Iris contact (value)	0.47507	1.188722	0.49068	0.756581
Odometer (value)	1134.627	535.6805	1280.739	292.0818
Emulsification near the capsule (# events)	5.73	2.344	7.83	2.749
Ultrasonic energy (value)	562.9	187.6672	480.389	117.0119
Damaged zonular fibers (value)	5.94%	11.26%	0.88%	2.28%
Posterior capsule torn (# events)	0.07	0.258	0.17	0.383
Anterior capsule torn (# events)	0.13	0.352	0.17	0.383
Time 3				
score	55.13	32.386	49.28	29.189
Time (time)	03:17.7	01:26.1	03:48.1	01:10.0
Incision stress (value)	3.578	8.2475	15.372	29.919
Iris contact (value)	0.08	0.164	0.93	2.691
Odometer (value)	1159.473	551.6873	1254.056	451.6154
Emulsification near the capsule (# events)	5.93	2.314	8.17	3.569
Ultrasonic energy (value)	581.81	192.61	538.65	131.86
Damaged zonular fibers (value)	0.33%	0.76%	3.84%	10.70%

Posterior capsule torn (# events)	0.2	0.414	0.17	0.383
Anterior capsule torn (# events)	0.13	0.352	0.17	0.383
Time 4				
score	55.33	34.632	51	27.144
Time (time)	02:56.6	01:03.8	03:26.5	01:00.2
Incision stress (value)	4.438	10.774	16.122	30.7878
Iris contact (value)	0.084	0.2913	0.193	0.2339
Odometer (value)	961.407	339.2714	1132.278	334.8689
Emulsification near the capsule (# events)	5.73	3.081	8.28	3.392
Ultrasonic energy (value)	581.127	180.1088	534.194	114.483
Damaged zonular fibers (value)	0.94%	2.08%	2.64%	5.17%
Posterior capsule torn (# events)	0.33	0.617	0.22	0.548
Anterior capsule torn (# events)	0.2	0.414	0.33	0.594
Time 5				
score	69.8	24.545	33.11	29.955
Time (time)	02:46.5	00:38.5	03:39.3	01:07.8
Incision stress (value)	4.911	10.9759	15.565	28.5511
Iris contact (value)	0.082	0.2195	0.618	0.9354
Odometer (value)	997.76	287.9293	1162.728	334.744
Emulsification near the capsule (# events)	5.67	2.289	7.22	2.901
Ultrasonic energy (value)	504.473	150.7908	551.706	152.4764
Damaged zonular fibers (value)	2.67%	10.11%	6.95%	16.33%
Posterior capsule torn (# events)	0.07	0.258	6.78	27.039
Anterior capsule torn (# events)	0.2	0.561	0.61	0.698

Chart 3. Aptitude Test Results Of The Trainees

Participants	Card Rotation	Cube Comparisons	Map Planning
A	44	13.5	17
B	65.5	15	13.5
C	57	21	13
D	54	17.5	12.5
E	39	7	12.5
F	59.5	4.5	12.5
G	34	6.5	10.5
H	50.5	3.5	9
I	45.5	9	7
J	55.5	6	6.5

Chart 4. Data Analysis for Navigation Level 3 Assessment In Training Versus Non-Training Group

Groups		Trained Group		Non-Training Group	
Parameters		Mean	SD	Mean	SD
Overall score	T1	79.00	3.464	57.00	13.904
	T2	80.10	4.332	62.10	14.617
	T3	81.60	3.921	61.80	18.831
Injured cornea area score	T1	.0000	.00000	-2.4830	4.42144
	T2	.00	.000	.00	.000
	T3	.0000	.00000	-1.6140	4.43373
Injured cornea area value	T1	.000000	.0000000	.248300	.4421438
	T2	.00	.000	.00	.000
	T3	.000000	.0000000	.161400	.4433730
Instrument slipped out of sphere no. Events	T1	15.70	6.111	24.20	12.209
	T2	12.00	4.447	23.30	13.392
	T3	11.50	4.696	24.40	10.936
Instrument slipped out of sphere score	T1	-19.00	2.539	-19.40	1.897
	T2	-18.40	2.633	-19.00	3.162
	T3	-17.80	3.458	-20.00	.000
Odometer score	T1	-.277400	.6402819	-14.981000	7.7560191
	T2	-.747000	2.3622214	-11.838000	8.4828779
	T3	.000000	.0000000	-10.249100	9.0366415
Odometer value	T1	81.930000	16.4006809	169.820000	57.7131951
	T2	77.950000	15.5139543	167.280000	87.3966412
	T3	68.680000	11.1660995	144.710000	60.9274696
Operating without red reflex duration	T1	0:00:00.100	0:00:00.316	0:00:04.800	0:00:08.203
	T2	0:00:00.000	0:00:00.000	0:00:04.700	0:00:07.558
	T3	0:00:00.000	0:00:00.000	0:00:03.800	0:00:08.189
Operating without red reflex score	T1	-.006670	.0210924	-2.311300	4.1093310
	T2	.000000	.0000000	-2.232000	3.6497970
	T3	.0000	.00000	-1.7850	4.00410
Time duration	T1	0:01:22.800	0:00:18.054	0:01:59.300	0:00:33.546
	T2	0:01:07.100	0:00:13.972	0:02:00.200	0:01:03.189
	T3	0:00:58.400	0:00:10.244	0:01:54.900	0:01:01.873
Time score	T1	-1.872000	.9580397	-3.931000	1.9236161
	T2	-.948900	.8027629	-3.987400	3.6046903
	T3	-.502520	.5297485	-3.676300	3.5392189
Time (with instruments inserted) duration	T1	0:01:13.700	0:00:15.449	0:01:57.300	0:00:32.941
	T2	0:01:07.100	0:00:13.972	0:01:58.600	0:00:59.161
	T3	0:00:57.800	0:00:09.151	0:01:43.900	0:00:37.584

Chart 5. Data Analysis for Anti-Tremor Level 3 Assessments

Groups		Trained Group		Non-Training Group	
Parameters		Mean	SD	Mean	SD
Overall score	T1	76.70	22.071	51.10	28.954
	T2	85.50	16.078	48.20	33.776
	T3	81.50	16.016	50.50	31.320
Average tremor value	T1	34.040000	2.2031291	35.790000	6.4129123
	T2	33.580000	1.9959960	38.440000	6.0183423
	T3	33.270000	2.6403072	38.030000	5.5651794
Operating without red reflex duration	T1	0:00:02.100	0:00:04.483	0:00:05.300	0:00:06.273
	T2	0:00:01.100	0:00:02.079	0:00:05.000	0:00:05.164
	T3	0:00:01.600	0:00:03.406	0:00:06.600	0:00:07.863
Operating without red reflex score	T1	-.944700	2.0761559	-2.503000	3.1020533
	T2	-.458330	.9599621	-2.324330	2.6493236
	T3	-.748700	1.6925671	-3.475556	3.8494776
Out of tolerance percentage score	T1	-22.20	21.364	-46.00	29.212
	T2	-14.00	16.303	-49.40	35.265
	T3	-17.80	15.929	-47.20	32.252
Out of tolerance percentage value	T1	11.10	10.682	23.00	14.606
	T2	7.00	8.151	24.70	17.632
	T3	8.90	7.965	24.00	16.885
Time duration	T1	0:00:37.800	0:00:08.942	0:00:47.800	0:00:07.480
	T2	0:00:33.700	0:00:08.512	0:00:43.100	0:00:04.606
	T3	0:00:34.700	0:00:07.273	0:00:41.400	0:00:08.758
Time score	T1	-.122330	.2484322	-.450100	.3438066
	T2	-.062200	.1966937	-.172556	.2264798
	T3	-.044100	.0728674	-.203690	.3641844
Time (with instruments inserted)duration	T1	0:00:36.300	0:00:06.734	0:00:44.300	0:00:06.977
	T2	0:00:33.700	0:00:08.512	0:00:41.900	0:00:04.771
	T3	0:00:34.700	0:00:07.273	0:00:40.500	0:00:08.923

Chart 6. Data Analysis for Anti-Tremor Level 4 Assessments

Groups		Trained Group		Non-Training Group	
Parameters		Mean	SD	Mean	SD
Overall score	T1	87.60	12.474	56.50	27.216
	T2	88.90	13.042	55.70	35.018
	T3	92.30	7.832	68.50	26.576
Average tremor value	T1	32.200000	2.4553796	36.870000	6.2055620
	T2	32.050000	2.2351982	37.540000	4.3249149
	T3	30.910000	2.2338059	34.710000	4.5488582
Operating without red reflex duration	T1	0:00:01.200	0:00:02.150	0:00:06.200	0:00:08.377
	T2	0:00:00.700	0:00:00.949	0:00:02.500	0:00:02.461
	T3	0:00:00.000	0:00:00.000	0:00:01.999	0:00:02.582
Operating without red reflex score	T1	-.543000	1.0165525	-2.914700	4.1216222
	T2	-.231600	.3520878	-1.062670	1.1392153
	T3	.000000	.0000000	-.855600	1.1838808
Out of tolerance percentage score	T1	-11.80	11.641	-40.40	26.830
	T2	-10.80	12.968	-43.40	34.808
	T3	-7.60	7.706	-30.60	26.966
Out of tolerance percentage value	T1	5.90	5.820	20.20	13.415
	T2	5.40	6.484	22.30	18.554
	T3	3.80	3.853	15.30	13.483
Time duration	T1	0:00:33.100	0:00:06.136	0:00:39.300	0:00:10.089
	T2	0:00:31.900	0:00:05.446	0:00:41.400	0:00:10.265
	T3	0:00:32.300	0:00:09.764	0:00:35.700	0:00:09.832
Time score	T1	-.013300	.0420583	-.191070	.3551690
	T2	.000000	.0000000	-.225710	.3941895
	T3	-.077950	.2193638	-.124200	.1879869
Time (with instruments inserted) duration	T1	0:00:33.100	0:00:06.136	0:00:38.000	0:00:09.967
	T2	0:00:31.500	0:00:04.994	0:00:40.700	0:00:10.750
	T3	0:00:32.300	0:00:09.764	0:00:34.500	0:00:09.571

Chart 7. Data Analysis for Forceps Level 4

Groups		Trained Group		Non-Training Group	
Parameters		Mean	SD	Mean	SD
Overall score	T1	99.10	.994	80.00	10.822
	T2	99.10	1.524	78.90	13.470
	T3	99.80	.632	86.10	8.543
Injured cornea area score	T1	.0000	.00000	-.6670	2.10924
	T2	.000	.0000	-1.570	4.9648
	T3	.00	.000	.00	.000
Injured cornea area value	T1	.000000	.0000000	.066700	.2109239
	T2	.0000	.00000	.1570	.49648
	T3	.00	.000	.00	.000
Injured lens area score	T1	.000000	.0000000	-.058220	.0707438
	T2	.000000	.0000000	-.053760	.1585502
	T3	.000000	.0000000	-.075060	.1218842
Injured lens area value	T1	.000000	.0000000	.093210	.1133513
	T2	.000000	.0000000	.085980	.2535536
	T3	.000000	.0000000	.120080	.1948878
Odometer score	T1	-.083000	.2117593	-13.696000	6.3616773
	T2	-.6330	1.46748	-12.7650	5.59797
	T3	-.042500	.1343968	-10.448000	7.5572126
Odometer value	T1	88.120000	10.3095210	134.500000	22.7559516
	T2	88.770000	13.1697507	126.600000	13.4263423
	T3	85.760000	10.1899951	121.230000	18.7722046
Operating without red reflex duration	T1	0:00:00.200	0:00:00.632	0:00:06.400	0:00:11.530
	T2	0:00:00.300	0:00:00.675	0:00:02.800	0:00:04.492
	T3	0:00:00.000	0:00:00.000	0:00:00.900	0:00:01.197
Operating without red reflex score	T1	-.083300	.2634177	-3.068970	5.7548141
	T2	-.088300	.2621323	-1.307970	2.1626317
	T3	.000000	.0000000	-.287330	.4518642
Time duration	T1	0:00:44.800	0:00:06.596	0:01:20.000	0:00:25.408
	T2	0:00:41.600	0:00:05.254	0:01:09.200	0:00:12.647
	T3	0:00:39.000	0:00:05.292	0:01:05.500	0:00:16.440
Time score	T1	-.294320	.2911233	-2.205800	1.4094344
	T2	-.144800	.1694139	-1.595200	.6962569
	T3	-.073200	.1456494	-1.429200	.8317089
Time (with instruments inserted) duration	T1	0:00:42.300	0:00:06.533	0:01:14.300	0:00:22.628
	T2	0:00:39.100	0:00:04.630	0:01:05.200	0:00:10.902
	T3	0:00:36.900	0:00:05.384	0:01:01.600	0:00:14.886

Chart 8. Data Analysis for Capsulorrhexis Level 8

Groups		Trained Group		Non-Training Group	
Parameters		Mean	SD	Mean	SD
Overall score T1 Overall score T2 Overall score T3	T1	71.90	14.372	23.60	31.249
	T2	80.60	15.443	35.60	28.258
	T3	72.30	7.790	28.50	29.797
Average radius of Capsulorrhexis value	T1	2.385000	.1981161	2.717000	.4062580
	T2	2.250000	.1559202	2.604000	.4025806
	T3	2.416000	.1683383	2.534000	.5363705
Centering (distance rhexis center to eye center) score	T1	24.910000	3.4070026	19.130000	8.3043563
	T2	24.900000	3.3095820	23.380000	4.9848214
	T3	23.280000	4.0174066	19.123000	9.3245054
Centering (distance rhexis center to eye center) value	T1	.253100	.1022985	.429900	.2596388
	T2	.252800	.0991349	.288020	.1665919
	T3	.293970	.1357534	.451390	.3558742
Deviation of rhexis radius from 2.5mm score	T1	29.830000	.5034327	23.580000	7.4106230
	T2	28.420000	3.5542775	24.779000	7.5964004
	T3	29.820000	.5692100	22.293000	11.0566743
Deviation of rhexis radius from 2.5mm value	T1	.196730	.1040750	.364910	.2633818
	T2	.249790	.1558450	.284680	.2894042
	T3	.146670	.1117850	.410750	.3174339
Injured cornea area score	T1	-.185200	.3492518	-3.630500	6.0289526
	T2	-.129500	.2145078	-4.758000	7.6708605
	T3	-.129600	.3030245	-2.796600	3.5475275
Injured cornea area value	T1	.018520	.0349252	.363050	.6028953
	T2	.012950	.0214508	.475800	.7670861
	T3	.012960	.0303024	.279660	.3547527
Local irregularity of Capsulorrhexis (spikes) score	T1	-2.00	6.325	-10.00	19.437
	T2	.00	.000	-4.00	12.649
	T3	-2.00	6.325	-10.00	14.142
Local irregularity of	T1	.10	.316	.50	.972
	T2	.00	.000	.20	.632

Capsulorrhexis (spikes) value	T3	.10	.316	.50	.707
Maximum radial extension of Capsulorrhexis score	T1	.000000	.0000000	-34.360000	28.6611312
	T2	.000000	.0000000	-12.155000	19.3641750
	T3	-.610000	1.9289894	-26.308000	31.6591180
Maximum radial extension of Capsulorrhexis value	T1	2.709000	.2102617	3.541000	.4585593
	T2	2.549000	.1472300	3.115000	.4817387
	T3	2.753000	.2238576	3.341000	.5992857
Non-horizontal instrument Events	T1	.00	.000	.60	.843
	T2	.10	.316	.40	.699
	T3	.00	.000	.20	.422
Non-horizontal instrument score	T1	.00	.000	-1.20	1.687
	T2	-.20	.632	-.80	1.398
	T3	.00	.000	-.40	.843
Operating without red reflex duration	T1	0:00:01.300	0:00:02.791	0:00:14.200	0:00:26.749
	T2	0:00:00.600	0:00:01.265	0:00:14.000	0:00:16.905
	T3	0:00:01.900	0:00:02.331	0:00:11.800	0:00:16.396
Operating without red reflex score	T1	-.545030	1.3109094	-4.420670	6.0304445
	T2	-.203400	.5146479	-6.590600	8.1904605
	T3	-.7370	1.03210	-5.5770	7.90610
Roundness of Capsulorrhexis score	T1	22.452000	10.6994806	13.840000	13.4713028
	T2	30.1530	12.18175	10.3620	12.13301
	T3	25.700000	7.7373553	13.864000	13.1456416
Roundness of Capsulorrhexis value	T1	.561100	.2673202	.346300	.3369972
	T2	.753900	.3047379	.259100	.3033881
	T3	.642300	.1933495	.346560	.3283417
Time duration	T1	0:03:02.200	0:00:42.601	0:03:30.400	0:01:32.292
	T2	0:02:58.600	0:00:54.179	0:03:12.700	0:00:49.607
	T3	0:03:13.600	0:01:09.420	0:02:49.300	0:01:03.444
Time score	T1	-2.684300	1.5406032	-3.798800	3.7714628
	T2	-2.451200	2.2177889	-3.115000	1.8569704
	T3	-3.109347	2.8023524	-2.257000	2.3919683
Time (with instruments inserted) duration	T1	0:02:40.600	0:00:41.802	0:02:39.300	0:00:56.071
	T2	0:02:37.400	0:00:55.205	0:02:37.400	0:00:48.314
	T3	0:02:51.400	0:01:09.401	0:02:14.600	0:00:51.104

Chart 9. Data Analysis for Bi-Manual Level4 Assessment

Groups		Trained Group		Non-Training Group	
Parameters		Mean	SD	Mean	SD
Overall score	T1	65.20	8.456	55.40	9.348
	T2	77.90	12.706	55.20	12.639
	T3	73.40	12.249	58.00	12.463
Instrument slipped out of sphere no. Events	T1	8.90	2.025	13.10	9.024
	T2	5.70	3.368	12.90	6.757
	T3	7.10	3.071	12.20	7.757
Instrument slipped out of sphere score	T1	-17.40	3.658	-17.60	3.978
	T2	-11.00	5.981	-17.00	4.643
	T3	-13.80	5.534	-16.80	3.293
Odometer score	T1	-15.4590	6.59784	-18.7180	4.05404
	T2	-10.1930	8.56124	-19.0600	2.28191
	T3	-11.679600	8.1507920	-17.709000	5.0970720
Odometer value	T1	148.70	36.317	206.70	92.513
	T2	136.830	50.8154	207.100	65.9822
	T3	137.00	37.526	177.50	45.695
Operating without red reflex duration	T1	0:00:01.100	0:00:02.601	0:00:12.100	0:00:14.387
	T2	0:00:00.800	0:00:02.201	0:00:11.500	0:00:16.854
	T3	0:00:00.500	0:00:01.581	0:00:13.400	0:00:16.153
Operating without red reflex score	T1	-.478000	1.1697369	-5.895300	7.1270468
	T2	-.371700	1.0528047	-4.846000	6.3167893
	T3	-.232000	.7336484	-6.073300	7.1558784
Time duration	T1	0:01:05.400	0:00:15.167	0:01:25.200	0:00:33.711
	T2	0:00:53.400	0:00:12.131	0:01:19.700	0:00:23.410
	T3	0:00:55.900	0:00:13.908	0:01:05.900	0:00:21.569
Time score	T1	-1.388700	.8359345	-2.494100	1.8798142
	T2	-.724400	.6495515	-2.176100	1.3042498
	T3	-.863800	.7464276	-1.420180	1.2040234
Time (with instruments inserted) duration	T1	0:01:04.500	0:00:14.386	0:01:24.600	0:00:33.925
	T2	0:00:50.900	0:00:09.457	0:01:19.700	0:00:23.410
	T3	0:00:53.400	0:00:11.568	0:01:05.900	0:00:21.569

Chart 10. Data Analysis for Cracking and Chopping Level 4

Groups		Trained Group		Non-Training Group	
Parameters		Mean	SD	Mean	SD
Overall score	T1	95.00	3.018	83.90	11.618
	T2	96.20	3.584	84.30	9.604
	T3	94.40	5.317	74.00	26.592
Instrument slipped out of sphere no. Events	T1	2.50	1.509	7.40	6.346
	T2	1.90	1.792	7.30	5.638
	T3	2.80	2.658	14.00	11.870
Instrument slipped out of sphere score	T1	-5.00	3.018	-11.60	7.412
	T2	-3.80	3.584	-12.40	8.154
	T3	-5.60	5.317	-15.00	5.981
Operating without red reflex duration	T1	0:00:00.000	0:00:00.000	0:00:07.600	0:00:10.814
	T2	0:00:00.000	0:00:00.000	0:00:05.900	0:00:06.657
	T3	0:00:00.000	0:00:00.000	0:00:06.100	0:00:07.923
Operating without red reflex score	T1	.000000	.0000000	-3.693000	5.3461638
	T2	.000000	.0000000	-2.822000	3.2204617
	T3	.0000	.00000	-2.9010	3.85352
Time duration	T1	0:00:26.600	0:00:08.099	0:00:45.800	0:00:22.890
	T2	0:00:21.700	0:00:05.599	0:00:40.100	0:00:19.581
	T3	0:00:21.700	0:00:09.166	0:00:59.700	0:00:29.952
Time score	T1	.000000	.0000000	-.681800	.8897423
	T2	.000000	.0000000	-.483900	.6459523
	T3	-.029600	.0936034	-1.235710	1.4774929
Time (with instruments inserted) duration	T1	0:00:26.600	0:00:08.099	0:00:45.800	0:00:22.890
	T2	0:00:21.700	0:00:05.599	0:00:39.300	0:00:20.715
	T3	0:00:21.700	0:00:09.166	0:00:59.500	0:00:29.643

Chart 11. Data Analysis for Phaco Divide & Conquer Level 6

Groups		Training Group		Non-Training Group	
Parameters		Mean	SD	Mean	SD
Overall score	T1	76.20	27.852	38.00	35.590
	T2	81.80	12.300	46.80	39.451
	T3	67.10	29.603	43.80	39.353
Anterior capsule torn no. Events	T1	.00	.000	.20	.422
	T2	.10	.316	.10	.316
	T3	.10	.316	.10	.316
Anterior capsule torn score	T1	.00	.000	-5.00	10.541
	T2	-2.50	7.906	-2.50	7.906
	T3	-2.50	7.906	-2.50	7.906
Capsule damage by ultrasonic energy no. Events	T1	.00	.000	.20	.422
	T2	.00	.000	.00	.000
	T3	.00	.000	.40	.699
Capsule damage by ultrasonic energy score	T1	.00	.000	-2.00	4.216
	T2	.00	.000	.00	.000
	T3	.00	.000	-4.00	6.992
Emulsification near the capsule no. Events	T1	.40	.699	1.10	2.132
	T2	.10	.316	.90	.738
	T3	.20	.422	1.60	2.366
Emulsification near the capsule score	T1	-1.30	2.111	-2.60	3.273
	T2	-.40	1.265	-3.00	2.108
	T3	-.80	1.687	-3.10	3.665
Non-horizontal instrument Events	T1	.10	.316	1.20	1.549
	T2	.10	.316	1.20	1.135
	T3	.20	.422	1.20	1.229
Non-horizontal instrument score	T1	-.20	.632	-2.40	3.098
	T2	-.20	.632	-2.40	2.271
	T3	-.40	.843	-2.40	2.459
Odometer value	T1	1194.90	271.965	1808.00	599.329
	T2	1200.10	218.801	1338.40	455.903
	T3	1139.10	228.865	1372.10	494.144
Posterior capsular torn no. Events	T1	.30	.675	.90	1.287
	T2	.00	.000	.60	.843
	T3	.40	.699	1.40	2.011
Posterior capsular torn score	T1	-10.00	21.082	-25.00	26.352
	T2	.00	.000	-20.00	25.820
	T3	-15.00	24.152	-25.00	26.352

Successful cracking attempts score	T1	37.340	5.6078	24.010	15.1425
	T2	37.340	5.6078	25.340	15.9666
	T3	36.000	9.0048	26.660	12.5865
Successful cracking attempts value	T1	2.80	.422	1.80	1.135
	T2	2.80	.422	1.90	1.197
	T3	2.70	.675	2.00	.943
Time duration	T1	0:05:19.400	0:01:36.901	0:06:00.400	0:02:15.241
	T2	0:05:13.300	0:01:12.890	0:04:42.600	0:01:21.328
	T3	0:04:50.500	0:01:21.321	0:04:16.100	0:01:38.408
Time score	T1	-1.322300	1.0739892	-1.776100	1.5004409
	T2	-1.255500	.8097191	-.984310	.7908110
	T3	-.999900	.9050260	-.677730	1.0446192
Time (with instruments inserted) duration	T1	0:05:12.100	0:01:36.424	0:05:49.800	0:02:16.473
	T2	0:05:03.700	0:01:13.306	0:04:16.600	0:01:19.453
	T3	0:04:42.400	0:01:21.734	0:04:02.800	0:01:39.488
Ultrasonic energy score	T1	-6.101300	3.5638156	-7.990800	5.4882490
	T2	-7.313000	3.8275233	-8.205000	2.9781211
	T3	-6.786000	2.9951709	-9.333000	4.9287502
Ultrasonic energy value	T1	462.10	118.234	523.90	153.800
	T2	504.60	107.128	530.00	83.651
	T3	489.10	86.495	561.10	137.780
Ultrasonic leakage score	T1	-1.673600	2.1128676	-1.428100	3.0517759
	T2	-2.084549	3.1545300	-.596000	.7856095
	T3	-1.829000	1.4317856	-1.774000	3.2978889
Ultrasonic leakage value	T1	318.30	94.920	284.80	125.492
	T2	356.30	90.014	288.70	57.465
	T3	338.60	60.987	306.50	122.122

Chart 12. Data Analysis of Pre and Post Training Assessment for Capsulorrhexis Level 8

Groups / Parameters		Pre-Training (n = 6)		Post-Training (n = 6)	
		Mean	SD	Mean	SD
Overall score	T1	12.00	27.950	76.33	11.911
	T2	17.50	22.143	78.67	17.558
	T3	9.17	14.784	73.00	7.510
Average radius of Capsulorrhexis value	T1	2.760000	.2824889	2.470000	.2068816
	T2	2.7800	.24000	2.2183	.18883
	T3	2.8867	.19180	2.5017	.12922
Centering (distance rhexis center to eye center) score	T1	19.238333	8.0383840	24.433333	4.3637904
	T2	18.453333	8.2944962	25.533333	3.5719276
	T3	16.408333	12.3418158	21.383333	2.5592317
Centering (distance rhexis center to eye center) value	T1	.423000	.2409971	.267667	.1310399
	T2	.446833	.2491477	.233833	.1067884
	T3	.521500	.3922936	.358333	.0767116
Deviation of rhexis radius from 2.5mm score	T1	26.533	5.8092	29.983	.0408
	T2	26.450	4.9383	27.367	4.4058
	T3	24.233	5.0369	30.000	.0000
Deviation of rhexis radius from 2.5mm value	T1	.314583	.2082197	.166717	.1037649
	T2	.309400	.1902922	.281316	.1894661
	T3	.386000	.1885651	.102167	.0628804
Injured cornea area score	T1	-11.075167	7.6828599	-.185167	.3704000
	T2	-3.211667	4.2604996	-.215833	.2458946
	T3	-12.445833	11.2086906	-.216000	.3780053
Injured cornea area value	T1	1.107517	.7682860	.018517	.0370400
	T2	.321167	.4260500	.021583	.0245895
	T3	1.244583	1.1208691	.021600	.0378005
Maximum radial extension of Capsulorrhexis score	T1	-29.316667	24.0697667	.000000	.0000000
	T2	-37.933333	31.1216752	.000000	.0000000
	T3	-34.091667	26.1101210	-1.016667	2.4903146
Maximum radial extension of Capsulorrhexis value	T1	3.430000	.4755208	2.796667	.1753473
	T2	3.620000	.4502444	2.566667	.1935631
	T3	3.5783	.36329	2.8583	.20760
Operating without red	T1	0:00:42.833	0:00:34.143	0:00:00.167	0:00:00.408
	T2	0:00:38.000	0:00:32.218	0:00:00.833	0:00:01.602

reflex duration	T3	0:00:29.000	0:00:16.260	0:00:01.500	0:00:01.643
Operating without red reflex score	T1	-14.4033	8.67036	-.0583	.14289
	T2	-13.436667	7.0035467	-.302833	.6633462
	T3	-13.3283	6.82179	-.4967	.66202
Roundness of Capsulorrhexis score	T1	6.915667	9.8614247	25.365000	11.3666772
	T2	13.930000	14.7760820	29.255000	14.0444918
	T3	8.411000	9.4149586	27.316667	8.6494894
Roundness of Capsulorrhexis value	T1	.172767	.2461598	.633833	.2842192
	T2	.348000	.3689537	.731167	.3514202
	T3	.210017	.2349654	.682500	.2164539
Time duration	T1	0:05:07.833	0:02:09.248	0:03:22.000	0:00:29.786
	T2	0:03:37.000	0:01:46.130	0:03:15.167	0:00:51.774
	T3	0:03:14.833	0:01:34.286	0:03:42.833	0:01:06.289
Time score	T1	-7.7433	5.46092	-3.4017	1.23167
	T2	-3.7300	4.59697	-3.1150	2.15464
	T3	-3.061667	3.5029155	-4.260833	2.7641534
Time (with instruments inserted) duration	T1	0:04:18.000	0:01:51.773	0:03:00.167	0:00:30.577
	T2	0:03:09.833	0:01:34.116	0:02:54.500	0:00:50.413
	T3	0:02:43.500	0:01:24.064	0:03:22.500	0:01:03.877

Chart 13. Data Analysis Pre & Post Training Assessment – Phaco Divide & Conquer Level 6

Groups		Pre-Training (n = 6)		Post-Training (n = 6)	
Parameters		Mean	SD	Mean	SD
Overall score	T 1	19.50	35.843	67.67	33.827
	T 2	11.00	17.053	78.00	14.353
	T 3	12.17	22.525	58.33	30.755
Anterior capsule torn no. Events	T 1	.33	.516	.00	.000
	T 2	1.00	.894	.17	.408
	T 3	.33	.516	.17	.408
Anterior capsule torn score	T 1	-8.33	12.910	.00	.000
	T 2	-16.67	12.910	-4.17	10.206
	T 3	-8.33	12.910	-4.17	10.206
Capsule damage by ultrasonic energy no. Events	T 1	.17	.408	.00	.000
	T 2	1.33	1.211	.00	.000
	T 3	1.17	1.169	.00	.000
Capsule damage by ultrasonic energy score	T 1	-1.67	4.082	.00	.000
	T 2	-13.33	12.111	.00	.000
	T 3	-11.67	11.690	.00	.000
Emulsification near the capsule no. Events	T 1	2.50	1.378	.67	.816
	T 2	5.67	3.983	.17	.408
	T 3	4.67	2.503	.33	.516
Emulsification near the capsule score	T 1	-5.50	1.378	-2.17	2.401
	T	-8.67	3.983	-.67	1.633

	2				
	T 3	-7.17	3.656	-1.33	2.066
Non-horizontal instrument insertion/removal no. Events	T 1	1.33	1.211	.00	.000
	T 2	1.83	2.137	.17	.408
	T 3	.67	.516	.17	.408
Non-horizontal instrument insertion/removal score	T 1	-2.67	2.422	.00	.000
	T 2	-3.67	4.274	-.33	.816
	T 3	-1.33	1.033	-.33	.816
Odometer value	T 1	2036.67	638.989	1266.00	259.938
	T 2	2338.33	898.297	1276.67	192.631
	T 3	1725.00	643.576	1246.67	184.572
Posterior capsule torn no. Events	T 1	2.17	1.941	.50	.837
	T 2	2.00	1.789	.00	.000
	T 3	1.67	1.633	.50	.837
Posterior capsule torn score	T 1	-33.33	25.820	-16.67	25.820
	T 2	-33.33	25.820	.00	.000
	T 3	-33.33	25.820	-16.67	25.820
Successful cracking attempts score	T 1	22.217	16.1567	37.783	5.4297
	T 2	17.767	18.2201	37.783	5.4297
	T 3	13.333	11.9406	33.333	11.1635
Successful cracking attempts value	T 1	1.67	1.211	2.83	.408
	T	1.33	1.366	2.83	.408

	T2				
	T3	1.00	.894	2.50	.837
Time duration	T1	0:06:57.833	0:02:11.682	0:05:49.167	0:01:48.627
	T2	0:07:01.500	0:03:14.410	0:05:35.833	0:01:23.132
	T3	0:05:39.667	0:02:31.316	0:05:16.667	0:01:34.396
Time score	T1	-1.19183	1.404593	-1.65333	1.200927
	T2	-1.188167	1.9059224	-1.507333	.9226726
	T3	-.518000	.8272637	-1.291333	1.0501733
Time (instruments inserted) duration	T1	0:06:15.833	0:01:48.583	0:05:42.167	0:01:47.823
	T2	0:06:41.333	0:03:11.036	0:05:25.500	0:01:24.420
	T3	0:05:21.833	0:02:34.134	0:05:08.500	0:01:34.796
Ultrasonic energy score	T1	-6.222833	3.9187544	-6.660000	4.0199552
	T2	-8.301667	4.8153065	-8.666667	4.2671239
	T3	-7.180000	3.7764004	-7.833333	2.1925297
Ultrasonic energy value	T1	474.17	109.638	472.00	142.754
	T2	532.00	134.569	542.33	119.614
	T3	501.00	106.136	519.50	61.458
Ultrasonic leakage score	T1	-.272500	.5644798	-2.107667	2.5273387
	T2	-1.138333	1.8540595	-2.958000	3.9088812
	T3	-.774000	1.3775561	-2.503333	1.3278203
Ultrasonic leakage value	T1	228.67	89.240	319.83	120.929
	T	263.83	127.398	379.33	112.774

	2				
	T3	242.016667	1.2244379E2	364.000000	51.9076102

Chart 14. Data Analysis of Trainees Performance in the PBP Curriculum vs Assessment for Capsulorrhexis Level 8

Group		Proficiency Level Score		Post Training Assessment	
Parameters		Mean	SD	Mean	SD
Overall score	T1	88.90	5.216	71.90	14.372
	T2	88.80	5.493	80.60	15.443
	T3	89.70	5.498	72.30	7.790
Average radius of Capsulorrhexis value	T1	2.367000	.1931062	2.385000	.1981161
	T2	2.363000	.1354047	2.250000	.1559202
	T3	2.424000	.1104737	2.416000	.1683383
Centering (distance rhexis center to eye center) score	T1	24.860000	3.6405738	24.910000	3.4070026
	T2	26.270000	3.3366817	24.900000	3.3095820
	T3	26.250	3.8367	23.280	4.0174
Centering (distance rhexis center to eye center) value	T1	.254100	.1091884	.253100	.1022985
	T2	.206670	.1082596	.252800	.0991349
	T3	.202250	.1270129	.293970	.1357534
Deviation of rhexis radius from 2.5mm score	T1	29.510	1.5495	29.830	.5034
	T2	29.650	.8182	28.420	3.5543
	T3	29.980	.0632	29.820	.5692
Deviation of rhexis radius from 2.5mm value	T1	.194203	.1213399	.196730	.1040750
	T2	.143538	.1282728	.249790	.1558450
	T3	.091831	.0958355	.146670	.1117850
Local irregularity of Capsulorrhexis (spikes) score	T1	.00	.000	-2.00	6.325
	T2	.00	.000	.00	.000
	T3	.00	.000	-2.00	6.325
Local irregularity of Capsulorrhexis (spikes) value	T1	.00	.000	.10	.316
	T2	.00	.000	.00	.000
	T3	.00	.000	.10	.316
Maximum radial extension of Capsulorrhexis score	T1	.00	.000	.00	.000
	T2	.00	.000	.00	.000
	T3	.000	.0000	-.610	1.9290

Maximum radial extension of Capsulorrhexis value	T1	2.679000	.2643840	2.709000	.2102617
	T2	2.658000	.1004213	2.549000	.1472300
	T3	2.702000	.1500222	2.753000	.2238576
Operating without red reflex duration	T1	0:00:00.800	0:00:01.317	0:00:01.300	0:00:02.791
	T2	0:00:00.600	0:00:00.699	0:00:00.600	0:00:01.265
	T3	0:00:00.500	0:00:00.707	0:00:01.900	0:00:02.331
Operating without red reflex score	T1	-.285000	.4750497	-.545030	1.3109094
	T2	-.148400	.2181367	-.203400	.5146479
	T3	-.178200	.2556481	-.737000	1.0320966
Roundness of Capsulorrhexis score	T1	37.580000	4.0482644	22.452000	10.6994806
	T2	35.610000	3.3087258	30.153000	12.1817478
	T3	36.630000	3.7780212	25.700000	7.7373553
Roundness of Capsulorrhexis value	T1	.939800	.1007558	.561100	.2673202
	T2	.890500	.0826885	.753900	.3047379
	T3	.915500	.0945730	.642300	.1933495
Time duration	T1	0:03:00.400	0:00:34.735	0:03:02.200	0:00:42.601
	T2	0:03:02.500	0:00:30.613	0:02:58.600	0:00:54.179
	T3	0:03:09.600	0:00:38.896	0:03:13.600	0:01:09.420
Time score	T1	-2.548000	1.3147775	-2.684300	1.5406032
	T2	-2.582700	1.2762992	-2.451200	2.2177889
	T3	-2.878200	1.6186410	-3.109347	2.8023524
Time (with instruments inserted) duration	T1	0:02:31.700	0:00:30.015	0:02:40.600	0:00:41.802
	T2	0:02:35.900	0:00:27.201	0:02:37.400	0:00:55.205
	T3	0:02:40.999	0:00:37.169	0:02:51.400	0:01:09.401

Chart 15. Data Analysis of Trainees Performance in the PBP Curriculum vs Assessment for Phaco Divide & Conquer Level 6

Groups		Proficiency Level Scores		Post Training Assessment	
Parameters		Mean	SD	Mean	SD
Overall score	T1	92.20	4.050	76.20	27.852
	T2	90.10	4.067	81.80	12.300
	T3	91.80	3.120	67.10	29.603
Anterior capsule torn no. Events	T1	.00	.000	.00	.000
	T2	.00	.000	.10	.316
	T3	.00	.000	.10	.316
Anterior capsule torn score	T1	.00	.000	.00	.000
	T2	.00	.000	-2.50	7.906
	T3	.00	.000	-2.50	7.906
Emulsification near the capsule Events	T1	.10	.316	.40	.699
	T2	.10	.316	.10	.316
	T3	.20	.632	.20	.422
Emulsification near the capsule score	T1	-.40	1.265	-1.30	2.111
	T2	-.40	1.265	-.40	1.265
	T3	-.50	1.581	-.80	1.687
Injured cornea area score	T1	-.148000	.4680171	-.055500	.1755064
	T2	-.296500	.7628166	-.055500	.1755064
	T3	-.03700	.117004	-.01850	.058502
Injured cornea area value	T1	.014800	.0468017	.005550	.0175506
	T2	.029650	.0762817	.005550	.0175506
	T3	.003700	.0117004	.001850	.0058502
Odometer value	T1	1243.70	315.392	1194.90	271.965
	T2	1231.00	335.534	1200.10	218.801
	T3	1216.20	319.593	1139.10	228.865
Posterior capsular torn no. Events	T1	.00	.000	.30	.675
	T2	.00	.000	.00	.000
	T3	.00	.000	.40	.699
Posterior capsular torn score	T1	.00	.000	-10.00	21.082
	T2	.00	.000	.00	.000
	T3	.00	.000	-15.00	24.152
Successful cracking attempts score	T1	40.000	.0000	37.340	5.6078
	T2	40.000	.0000	37.340	5.6078
	T3	40.000	.0000	36.000	9.0048
Successful cracking attempts value	T1	3.00	.000	2.80	.422
	T2	3.00	.000	2.80	.422
	T3	3.00	.000	2.70	.675
Time duration	T1	0:05:24.700	0:01:48.570	0:05:19.400	0:01:36.901
	T2	0:05:13.900	0:01:20.117	0:05:13.300	0:01:12.890

	T3	0:05:10.800	0:01:29.527	0:04:50.500	0:01:21.321
Time score	T1	-1.384800	1.2030930	-1.322300	1.0739892
	T2	-1.259900	.8884156	-1.255500	.8097191
	T3	-1.225200	.9966916	-.999900	.9050260
Time (instruments inserted) duration	T1	0:05:05.300	0:01:48.040	0:05:12.100	0:01:36.424
	T2	0:04:58.400	0:01:19.633	0:05:03.700	0:01:13.306
	T3	0:04:54.400	0:01:30.098	0:04:42.400	0:01:21.734
Ultrasonic energy score	T1	-4.784000	3.0742341	-6.101300	3.5638156
	T2	-5.959000	2.9393667	-7.313000	3.8275233
	T3	-4.887900	2.7067692	-6.786000	2.9951709
Ultrasonic energy value	T1	433.90	85.979	462.10	118.234
	T2	466.30	83.884	504.60	107.128
	T3	436.60	76.295	489.10	86.495
Ultrasonic leakage score	T1	-.656300	1.0959071	-1.673600	2.1128676
	T2	-1.415500	1.6726179	-2.084549	3.1545300
	T3	-.835900	1.2045136	-1.829000	1.4317856
Ultrasonic leakage value	T1	284.30	59.206	318.30	94.920
	T2	330.70	59.431	356.30	90.014
	T3	303.60	57.361	338.60	60.987

APPENDIX II

Survey 1 – Background information of the participants

Trainees Demographic Information Sheet

Date: ____ / ____ / ________

Name: ____________________

Duration of Ophthalmology Training: ________ months

Current Hospital: _______________ **Position:** SHO Registrar

Age: __________ **Sex:** Male Female

Hand Dominance: Right Left **Phaco Hand Piece:** Right Left

Direction of Capsulorrhexis: Clockwise Counter clockwise

Head position: Frontal Temporal approach

Training History

Microsurgical skill course (RCO London) attended: Yes No

Any other phaco skill course: ________________________________

Hour of EYESi simulator trained (not including assessment): __________

Wet lab training: Never Seldom Frequent ________ Hours/Week

Number of full case completed: __________

Number of modular case (if not yet complete one full case): __________

Length of training in Ophthalmology when completed the first full case: ________ Months

Number of modular cases before completed the first full case: __________

Survey 2 – Feedback from trainees after attended the didactic lecture

Didactic Cataract Surgery Lecture Feedback Questionnaire

Please respond to each of the following items in terms of how true it is for you with respect to your learning in this lecture. Use the scale:

1	2	3	4	5	6	7
not at all true			somewhat true			very true

Q1. Do you find this tutorial is structured and has clear objective?

1	2	3	4	5	6	7
not at all true			somewhat true			very true

Q2. Do you find the content interesting?

1	2	3	4	5	6	7
not at all true			somewhat true			very true

Q3. Do you find the content useful?

1	2	3	4	5	6	7
not at all true			somewhat true			very true

Q4. Does animation help you to understand the surgical skills better?

1	2	3	4	5	6	7
not at all true			somewhat true			very true

Q5. Do you understand the steps in cataract surgery after the course?

1	2	3	4	5	6	7
not at all true			somewhat true			very true

Q6. Would you recommend this course to next batch of SHO?

1	2	3	4	5	6	7
not at all true			somewhat true			very true

Q7. Do you need another session to consolidate the content of this course?

1	2	3	4	5	6	7
not at all true			somewhat true			very true

Survey 3 – Feedback from trainees after attended the didactic lecture

Perceived Competence for Learning

- Didactic Cataract Surgery Lecture -

Please respond to each of the following items in terms of how true it is for you with respect to your learning in this lecture. Use the scale:

1	2	3	4	5	6	7
not at all true			somewhat true			very true

1. I feel confident in my ability to learn this material.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

2. I am capable of learning the material in this lecture.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

3. I am able to achieve my goals in this lecture.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

4. I feel able to meet the challenge of performing well in cataract surgery.

1	2	3	4	5	6	7
not at all true			somewhat true			very true

Demographic Data:

Position: SHO Registrar

Number of cataract cases attempted/done: 0, 1-25, 26-50, 51-100, >100

Survey 4 – For participants who completed the EYESi simulator training program

Training on the EYESi simulator:

1) I gained understanding for cataract surgery

1	2	3	4	5	6	7
not at all true			somewhat true			very true

2) I gained techniques relevant to cataract surgery

1	2	3	4	5	6	7
not at all true			somewhat true			very true

3) I gained confidence in myself to perform cataract surgery

1	2	3	4	5	6	7
not at all true			somewhat true			very true

4) I become a better surgeon

1	2	3	4	5	6	7
not at all true			somewhat true			very true

5) I learned skills that are useful when I perform surgery on live patient

1	2	3	4	5	6	7
not at all true			somewhat true			very true

6) I learned BAD techniques from the simulator, which makes my surgery worse

1	2	3	4	5	6	7
not at all true			somewhat true			very true

7) I developed better hand and eye coordination

1	2	3	4	5	6	7
not at all true			somewhat true			very true

8) I got better at capsulorrhexis

1	2	3	4	5	6	7
not at all true			somewhat true			very true

9) I got better at phaco divide and conquer

1	2	3	4	5	6	7
not at all true			somewhat true			very true

10) Every trainee should be trained to proficiency on EYESi simulator as part of their surgical training

1	2	3	4	5	6	7
not at all true			somewhat true			very true

11) Is the proficiency level too low or too high?

1	2	3	4	5	6	7
Too Low			Appropriate			Too High

Survey 5 – Trainee's feedback for the simulator trainer

Learning Climate Questionnaire

This questionnaire contains items that are related to your experience with your instructor in this class. Instructors have different styles in dealing with students, and we would like to know more about how you have felt about your encounters with your instructor. Your responses are confidential. Please be honest and candid.

1. I feel that my instructor provides me choices and reasons.

1	2	3	4	5	6	7
strongly disagree			neutral			strongly agree

2. I feel understood by my instructor.

1	2	3	4	5	6	7
strongly disagree			neutral			strongly agree

3. My instructor conveyed confidence in my ability to do well in the course.

1	2	3	4	5	6	7
strongly disagree			neutral			strongly agree

4. My instructor encouraged me to ask questions.

1	2	3	4	5	6	7
strongly disagree			neutral			strongly agree

5. My instructor listens to how I would like to do things.

1	2	3	4	5	6	7
strongly disagree			neutral			strongly agree

6. My instructor tries to understand how I see things before suggesting a new way to do things.

1	2	3	4	5	6	7
strongly disagree			neutral			strongly agree

Survey 6 – Maslow's Learning Needs Survey For Ophthalmic NCHDs in Phacoemulsification Training

Training in Ophthalmology: ________ months
Post: SHO Registrar SpR (please circle)
Hospital: ____________________
Number of cases done so far: 0-50, 51-100, 101-200, over 200 (please circle)

Does your cataract training in operating room allow you to achieve the following aspects of learning?

	1 Strongly Disagree	2 Disagree	3 In between	4 Agree	5 Strongly Agree
Comfortable Environment					
Confident that can express yourself					
Feel part of a group					
Becoming self confident					
Have the opportunity to master skills					
Supported in achieving potentials					